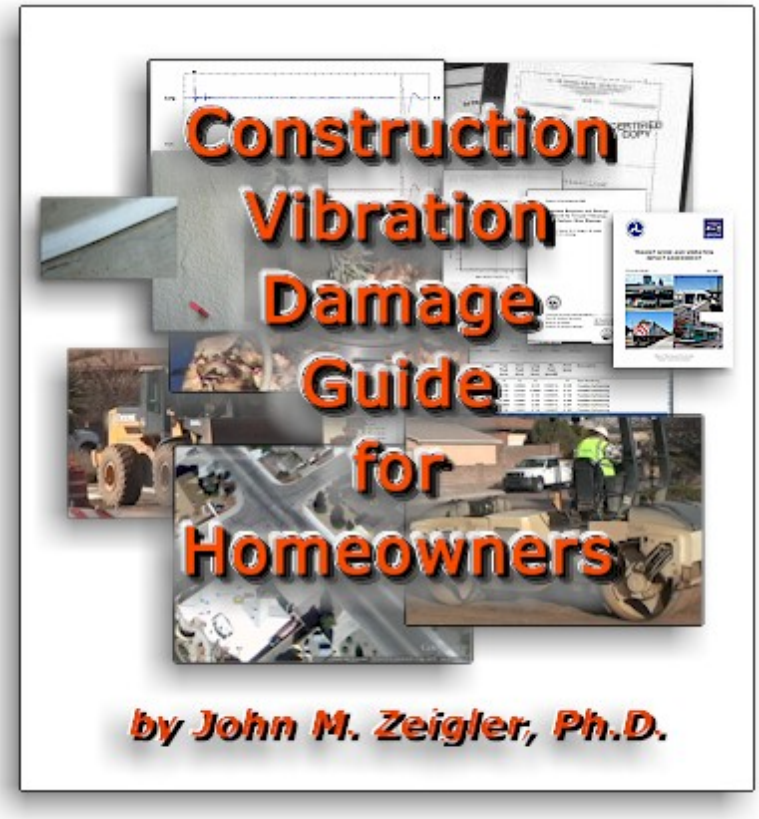

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The

Construction Vibration Damage Guide

for Homeowners

Edition 2.2

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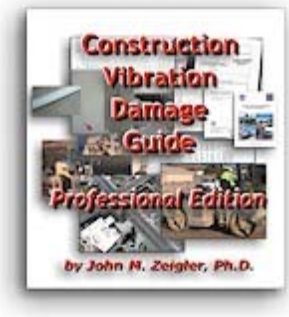
CVDG Homeowners and Pro Contents

©Construction Vibration Damage Guide (CVDG) for Homeowners and Professional Edition

Table of Contents



You'll find the Table of Contents for both the free CVDG for Homeowners and the extended Professional Edition just below. The Professional version is directed at attorneys, contractors, educators, geo-technical firms, those with vibration damage claims, those preparing a vibration damage claim for possible litigation and others with a need to know more details. The *Guide* does not specifically cover vibration damage from machine tools in factory settings, health effects of vibration, or any other form of heavy equipment vibration than that used in construction, although some of the information may be generally useful in some of those other settings.

Documents with hyperlinks are part of the free CVDG and are available online as web pages or as a free downloadable PDF. Documents unique to the Pro Edition are shown in **bold** below. Those documents are not included with the free version of the CDVG and are not offered online. The CVDG Pro is available for purchase by credit card or PayPal account, with same day delivery in most cases, from our Order the CVDG Pro page at http://vibrationdamage.com/order_the_cvdg_pro.htm.

Disclaimer: The Construction Vibration Damage Guide is not offered, and should not be considered, as legal advice. Seek the advice of an attorney with construction vibration damage claim experience and knowledge, if you need legal help. Trademarks appearing in the CVDG are the properties of their respective owners and are used in the CVDG only for the purpose of identification.

CVDG *for Homeowners and Professional Editions*
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CVDG Foreword

The *Construction Vibration Damage Guide for Homeowners* (CVDG, ©Copyright 2013-2014 John M. Zeigler) was developed for use by those who feel that they might have experienced damage to a home or building from construction vibration. It will also help those homeowners who have construction planned for their area and wish to take steps to avoid damage to their homes. It includes a great deal of scientific and technical information, written for non-scientists, which attorneys, educators and responsible construction firms may find valuable, as well.

The Homeowners version of the *Guide* is available free for personal, non business use to homeowners. The copyrighted CVDG may not be copied, offered in PDF format or reproduced in any form, at any length, on other web sites. The page (http://www.vibrationdamage.com/vibdamguide.htm) may be linked by other sites or cited as the source of the *Guide*.

The *CVDG* is based on almost four years of daily experience and scientific work in this area by Dr. John Zeigler, arising out of extensive road reconstruction vibration damage done to his own home and many others in the area. This extensive damage was initiated by repeated pounding on pavement with a large tracked excavator (see video frame grab at right) at multiple locations - done to break the existing asphalt. The pounding was carried out both before and **after** notification of the contractor and the work sponsor of the damage and its cause. Dr. Zeigler was the primary scientific consultant in his own case, because there was very limited real scientific expertise and experience in vibration damage and monitoring accessible in his area. Although the CVDG is not a retelling of Dr. Zeigler's example and case, it does use examples from it to illustrate what can happen to cause vibration damage and how a vibration damage claim can proceed.

The *CVDG* is not intended to be a "how-to" manual describing the "ins and outs" of suing contractors. Many construction contractors are reasonable, professional and honest. An honest contractor will try to help with any well-founded damage claim. However, if you have a lot of damage (e.g. almost $250,000 in the author's example), you may find it much more difficult to deal with the contractor or its insurer. Often, damage occurs because the **contractor employees were carrying out operations in non-accepted ways and/or in direct violation of the contractor's own policies** (see above). The result is that you will have to pursue the claim or pay for the damage yourself. The CVDG will help those facing this problem to increase their chances of fair treatment by the contractor, insurers and the legal system.

The *CVDG* furnishes readers who may be unfamiliar with this area the facts, knowledge and understanding to pursue effectively a **legitimate** claim. In **mostly non-technical language**, it describes what you can do to avoid damage, how to document a legitimate claim for damages, how to evaluate options in making a claim for damage

reimbursement, what operations are most likely to cause damage, how to understand vibration monitoring results, what resources are available on the Internet and much more. Although the technical issues are not hard to understand for anyone with some high school level background in physics, the language of the ground vibration literature may not be within reach of everyone. The *Guide* attempts to address this problem by **offering simple analogies and defining critical terms**, so that people with non-technical backgrounds can read at least the most important of the ground vibration literature and gain some understanding of it. Of course, I also hope that this Guide will help those who **must** get an attorney to prepare for a discussion of their claim and, perhaps, help them in educating the attorney on some important technical issues.

Especially when damage is reported, vibration monitoring is often initiated by contractors as part of their legal defense. The *Guide* provides information to help non-scientists **understand ground vibration monitoring and the results** to find out whether claims based on them are really justified. It has been my experience that such claims are often overstated or, all too often, outright false. Unfortunately, even the construction companies who sponsor such work may be ill-prepared to read and understand vibration monitoring data acquired at their behest. Sometimes to their misfortune, they must depend only upon the word of their vibration monitoring sub-contractor. We have seen clear examples where some vibration monitoring sub-contractor employees were incompetent, poorly trained, inadequately supervised, unprofessional and flatly dishonest. Construction companies may find the *Guide* valuable in understanding and validating the vibration monitoring testing results and procedures, which they have contracted with others to perform. The Professional Edition of the CVDG develops these areas more fully, with over twice the content for those whose business it is to read, use or create vibration monitoring data.

The CVDG is a combination of scientific analysis, tips for identifying damage and advice for dealing with many elements of a vibration damage claim, based on nearly 4 years of near-constant work in this area by Dr. Zeigler. Just like scientific review papers, the CVDG carries references to original scientific work and critical analysis of the work, so that the reader unfamiliar with the field can gain an understanding of it relatively quickly. In this case, the use of the word "critical" is intended in the scientific sense of understanding the implications of the work, not in the sense of being "negative" about it.

Unlike a scientific review paper, the **CVDG avoids the use of the more precise scientific jargon wherever possible and explains the meaning of jargon in lay terms**, when some understanding of it is necessary. Since the CVDG is written for a non-technical audience, its wording is as non-technical as the subject matter allows. The non-technical language of the CVDG places some technical limitations on it. References to original scientific work, written in the more precise language of science, are included liberally within the CVDG to allow readers to verify and supplement the statements within the CVDG by reference to the original articles.

The CVDG reflects its origin as a web-based publication in that given topics may be mentioned, or even discussed to some degree, in several places. Since a site owner can't always know or predict where a reader will enter or exit his web site or the path the visitor will take through the site, individual web pages must be reasonably self-contained. Each individual page must cover many of the major points, at least within its area of focus, even if other pages on the site elaborate on those topics. Thus, there is

some duplication of content on some different pages, even though the extent of the coverage of each topic varies. I hope that readers of the CVDG will understand the reason for the limited restating of important points on multiple pages. **I strongly recommend that readers of the CVDG read it in full, before proceeding with other actions**. It has so much information that relevant information for a given situation can be missed entirely in a short scan of the document.

The *Construction Vibration Damage Guide for Homeowners* has a lot of information, but it has been **deliberately shortened and greatly simplified**, so that those without technical or legal backgrounds can get more benefit from it. **Some of the things which I've had to gloss over or omit entirely include: interpretation of and analysis procedures for vibration monitoring data, proper setup and use of vibration seismographs, extensive discussion of vibration damage scientific literature, legal advice and counsel, proper use of construction equipment, appropriate expert counseling on scientific and legal issues, contractual responsibilities of contractors, advice in dealing with insurers, understanding of construction operations, responsibilities of project sponsors and engineering analysis of damage and its causes, to name just a few**. Many of these issues are discussed in more detail in the CVDG Professional Edition. You will probably also need help from a **good** attorney and **good** experts, if you can't settle your claim. I place the emphases in the last sentence because, as with all other groups of people, not all attorneys and experts are created equally.

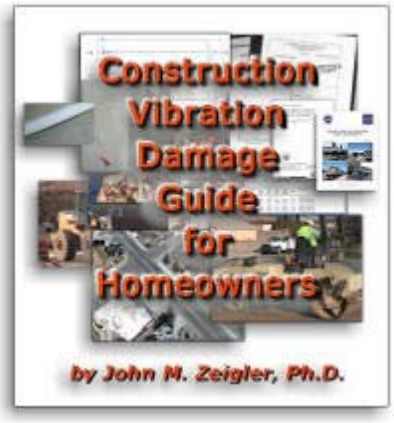
To learn more about construction vibration damage via Vibrationdamage.com's web pages, begin with the CVDG Table of Contents or Introduction page, then follow the links to other parts of the CVDG. You can also download a full copy of the CVDG, web navigation and ad-free, in PDF format. The extended version of the CVDG, the CVDG Professional Edition, can be purchased by those who need more information or those who wish to use the CVDG in business activities or settings.

Disclaimer: The Construction Vibration Damage Guide is not offered, and should not be considered, as advice on the law in any jurisdiction or form. Seek the advice of an attorney with construction vibration damage claim experience and knowledge, if you need legal help. Trademarks appearing in the CVDG are the properties of their respective owners and are used in the CVDG only for the purpose of identification.

CVDG Overview

Construction Vibration Damage Guide (CVDG) for Homeowners

Overview



The free *Construction Vibration Damage Guide for Homeowners* (*CVDG*, ©Copyright 2013-2014 John M. Zeigler) was developed for use by those who feel they might have experienced cracking or other damage to their homes from construction vibration or those who have concerns about planned construction in their area. The *Guide* can be used by those who are considering **non-legal remedies or legal action** and those who simply want to find out about vibration damage due to pending construction in their area. **The Guide has over 200 color photos, diagrams and other illustrations to illuminate concepts and issues**. You can view it as web pages by following the links on this page or download a free PDF version of the CVDG, which has all the ads, navigation and other web-related material removed for easier reading.

What's in the CVDG

The free *CVDG* describes how to document a legitimate claim for damages, how to evaluate options in making a claim for vibration damage reimbursement and **much more**. The full text of the CVDG Table of Contents is below. Although not the focus of the *CVDG*, there is a substantial discussion of mine and quarry blasting vibration science. Also included is a great deal of scientific and technical information, written for non-scientists, that those handling or having construction vibration damage claims may find valuable, as well. These more technical topics are further explored and developed in the **Professional Edition of the CVDG, which is over twice the length of the free CVDG.**

CVDG Table of Contents

The CVDG is a layman's summary of the science and technology of construction vibration damage. It is written in non-technical language, although many explanations of technical terms and concepts are provided, to allow those with non-technical backgrounds to understand the terms used in the field. **It has a Flesch-Kincaid reading ease score of 45 and a Flesch-Kincaid Grade Level of 12, so those with a high school or equivalent education**

should be able to read and understand it with little difficulty. I hope that, with the introduction provided by the CVDG, non-scientists will be placed in a better position to handle vibration damage claims with a minimum of expense and stress.

The CVDG, in both versions, is based on experience in the United States, although those in other countries should find its content generally applicable in the great majority of areas discussed. CVDG readers in countries other than the U.S. will need, in particular, to learn the vibration standards relevant in their locales. The CVDG page, Vibration Standards, has a summary of the designations for these in most developed countries.

Reproducing the CVDG

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Viewing and Using the CVDG

The *CVDG* **can be viewed either as web pages on Vibrationdamage.com or in full as a single free PDF document**. I recommend that you **view the** *Recognizing Damage* **section of the Guide as web pages**, if you want to see full size versions of some damage photos present as thumbnails there. To learn more about construction vibration damage via our web pages, begin with the Table of Contents or Introduction page, then follow the links to other parts of the CVDG. It may be helpful to **keep open the hyperlinked CVDG Table of Contents page** in a separate tab or window to allow easier online navigation of all the CVDG pages.

The **free PDF version** of the 110+ page *Guide* can be obtained from the Vibrationdamage.com Downloads page. The PDF version bears all of the content as the web version pages, **plus several PDF only pages**. The web page navigational material, ads and other web page structures are removed, so that the pages can be read more easily offline. The PDF has an embedded index for fast searching of the text. It is formatted for binding in a 3-ring binder or portfolio. Since both the CVDG web pages and the corresponding PDF compilation are upgraded regularly, those who have downloaded it or read the site previously may want to **check for upgrades** occasionally.

Disclaimer: The Construction Vibration Damage Guide is not offered, and should not be considered, as advice on the law in any jurisdiction or form. Seek the advice of an attorney with construction vibration damage claim experience and knowledge, if you need legal help. Trademarks appearing in the CVDG are the properties of their respective owners and are used in the CVDG only for the purpose of identification. Information appearing in the CVDG is believed correct, but the CVDG is provided "as-is". It is not guaranteed or warranted in any way, nor is your use of it warranted or guaranteed.

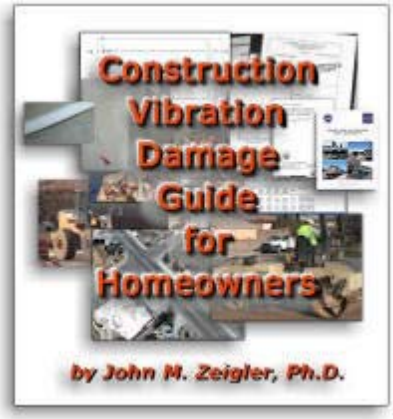
See if We Can Help You!

If you're interested in exploring whether we can help in your construction vibration damage issues, as a homeowner, an attorney or responsible contractor, contact us now. Initial consultations are free and confidential, without obligation. You can reach us at drzeigler@vibrationdamage.com or call us at the contact numbers on the Contact Us page.

CVDG Intro

The *Construction Vibration Damage Guide for Homeowners* (*CVDG*)

Introduction



This section of the *CVDG* ("the *Guide")* has summary information for those who have developed **cracking in walls, damage to home mechanical systems, doors and windows misalignment, damage to concrete and concrete blocks, exterior stucco cracks and more** while road construction, or any other heavy equipment construction causing ground vibration, has been occurring within hearing distance. These homeowners may have real concerns about whether the construction caused the damage to their home or property and how they should deal with that problem.

This and linked pages in the *CVDG,* which provide more detail on all the topics mentioned in this section, are **directed mostly at homeowners** facing potential or existing construction vibration damage to their homes. Responsible contractors with an interest in understanding vibration monitoring results, vibration monitoring contractors, university educators and attorneys working in vibration damage litigation may also find parts of the CVDG useful. **The *Guide* is written in non-technical language**, although it defines, discusses and explains many scientific and technical concepts and issues. **The tips here and on linked pages in the *CVDG* should not be considered as attorney or legal advice (see disclaimer)**. At the top, left and bottom of this and all other pages of the web versions of the CVDG, you'll find links to more extensive discussions of individual topics in the *CVDG*, as well as links to other parts of Vibrationdamage.com. The CVDG page, Closing Thoughts, has a broader summary of the CVDG contents and conclusions.

Background

Most people living in towns and cities will have road or other construction using heavy equipment occurring in the immediate area of their homes or businesses sooner or later. Many construction companies are professional, honest and responsible. But, there are some whose behavior is not so admirable. Unfortunately, **misbehavior and misuse of heavy equipment** by construction workers are all too common. **When misused, or used properly too close to homes and other properties, heavy construction equipment-caused vibration can, and does, damage structures**. This fact

is part of the reason why contractors must carry **insurance for most projects**. Although much of what can be found on the Internet regarding this subject says, in effect, that construction can't damage structures, **such statements are often based on selective analyses of the scientific literature and inappropriate application of clearly unsuitable vibration standards**, if they are based on any scientific understanding at all.

Construction vibration damage often takes place without the immediate knowledge of the nearby residents, simply because they haven't thought to look for it. Only later, as damage becomes more extensive and apparent, will some homeowners note it. Those homeowners who find the damage may not make the connection between it and the construction work, because they are unaware that vibration damage to structures can occur in construction using heavy equipment. Of course, since most folks work during the day, homeowners often do not know that potentially damaging vibrations have taken place in their homes.

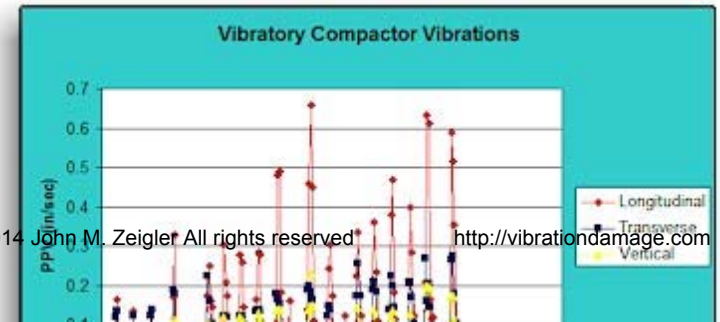
Most people don't have the scientific knowledge and legal experience to document a vibration damage claim properly, deal with the contractor, its insurer and its attorneys or understand vibration monitoring data acquired on behalf of the contractor. Without proper knowledge, preparation, documentation and analysis, homeowners simply don't have a chance against a construction company and insurers determined to evade responsibilities for construction damage. **The *CVDG* will help you gain the necessary knowledge.**

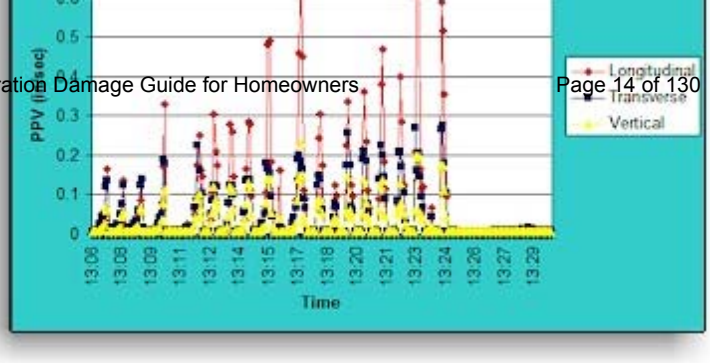
A good place to start in the CVDG, if you're unfamiliar with ground vibration science and terminology, is our page Vibration 101. This section of the CVDG has a basic introduction to ground vibration and its effects. Other pages in the CVDG expand greatly on this basic information, but, if you're not a scientist, reading it will help you in understanding the other CVDG pages.

How Damage Can Happen

Most construction companies, and the vibration monitoring companies and consultants who work for them, will tell you, at a minimum, that construction does not cause damage to structures in the normal course of work. This view, while perhaps self-serving, is justified in many cases. But, it hinges on the definition of "normal course", the nature of the equipment used, the location of the work relative to structures and the way in which the equipment is employed in the job.

Under pressure of deadlines and monetary penalties for failure to meet them, or even just for "fun", construction company employees will sometimes take "shortcuts". Many of these shortcuts the construction company itself would not sanction. Even some "properly done" construction operations, e.g. impact pile driving and use of vibratory compactors (photo at left) in paving operations (see diagram at right for recorded vibrations in a road reconstruction project), are known to produce vibrations which can cause damage if close enough to the nearby property. Most of the vibratory compactor vibrations





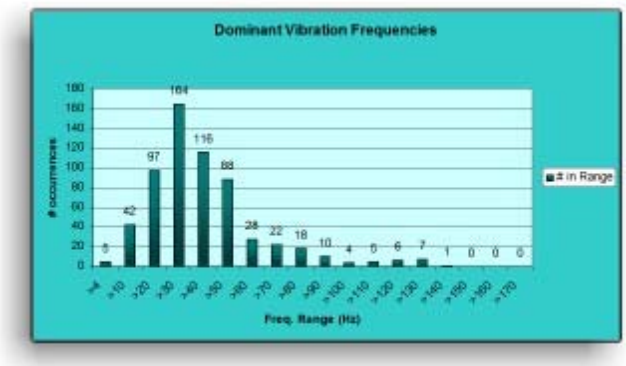
shown in the diagram at right violate some or all of the **relevant** construction-based vibration standards. For more on the likelihood of construction-related damage, see our page, Is Damage Possible?

Single Event vs. Continuous Ground Vibration

Most ground vibration standards, and statements made about them, are ultimately based on studies of blasting vibration in mine and quarry operations. It is important to understand that such studies, and the standards based upon them, estimate **damage probabilities for a group of structures from a single blasting event, not the probabilities of multiple events damaging a single structure**. These standards, and the studies supporting them, have much value when properly applied to blasting situations, since **blasting creates relatively infrequent vibrations lasting, at most, a few seconds**.

However, blasting standards are not appropriate for **construction settings, where vibration can continue for minutes, hours, weeks, months or even years in some large projects** (see above for a representative example of vibration in a short period at one home location in a road reconstruction project). In one example, a road construction contractor's own production of partial vibration monitoring data indicated that it **violated relevant road construction vibration standards at least six hundred times in the course of a project**. Extensive damage of similar appearance was done to a large number of homes along the path of the work.

Calculations based on actual road reconstruction data show that **total construction vibration exposure in a single day can be from tens to well over a hundred times that experienced from blasting** at an active mine. For details on this, see Resonance/Fatigue. Technical details of the calculations and further discussion can be found on the CVDG Pro page, Vibration Exposure.



Continuous or near-continuous construction vibration brings into play resonance and fatigue effects, which are far less significant in relatively infrequent and widely spaced mine blasting events. Fundamentally, blasting vibrations last for a few seconds at most, less than the duration of the vibrations induced in a home. Construction vibrations last far longer than the natural duration of home vibrations, allowing resonance and fatigue effects far more time to do damage. Further, construction vibrations, like the set of data at left, have frequencies which are mostly within the resonance frequency regimes of homes. There is very limited scientific study of the effect of long-lived construction vibrations on homes, as opposed to the far more extensive, but largely inapplicable, blasting studies.

Thus, **use of mine blasting-based standards in construction situations not involving blasting is misleading and ill-advised**. Worse yet, because of the nature of the way ground vibrations move through soil, **properties a few hundred yards away from the construction can be damaged by vibrations** in some circumstances.

Handling Construction Vibration Damage to Your Home

If you have construction ongoing in your area (e.g. within hearing distance), you should **immediately** examine your house for signs of cracking, particularly diagonal cracks in drywall, plaster or stucco at the corners of wall penetrations (doors, windows), and cracks in concrete patios, driveways and slabs. It is best to document carefully the condition of your house, even if you don't see cracking at that time, as cracking may develop later or become more visible. Construction damage can take months or even years to become fully apparent, so any increase in cracking or other damage to the house is cause for concern.

The best approach is to head off vibration damage problems prior to construction by documenting the house condition and registering your concerns in public comment meetings. If you end up with damage, there are some things you should keep in mind. Construction companies receive complaints with some frequency about damage alleged to have been caused by their activities. They are experienced in dealing with complaints. Many will likely discount as "pre-existing damage" (see Counterarguments page, CVDG Pro) any claim you make based solely on your statements. You must have documentation of the damage and substantial evidence of a causal link to the construction activity (see Damage Causation in CVDG Pro), at a minimum. If your claim is substantial, it will most likely be ignored without this evidence and more. That said, the fact that construction companies usually must carry insurance for their work indicates, by itself, the potential for damage, even though it doesn't always occur.

Damage Classification and Documentation

Damage to structures is usually classified as "structural" or "cosmetic". "**Structural damage**" refers to any type of change which could compromise the stability of the structure. Its existence is usually determined by a structural or civil engineer who examines the damage. Structural damage is often hidden or disguised by overlying cosmetic damage and can involve damage to mechanical systems (heating, air conditioning, plumbing) in the house, as well as to the structure itself.

"**Cosmetic damage**" is basically everything else which affects the appearance of the house: cracking of drywall or plaster, nail or screw "pops", exterior damage to the finish of the house, cracking of concrete driveways or patios, surrounding property wall damage, doors and windows out of alignment due to shifting of the structure, and so forth. Some types of construction-caused damage can look very similar to "settling damage" or can involve settling, so you will need to try to differentiate the two. This is especially relevant in light of the high likelihood that a contractor and its representatives will say the damage is pre-existing or due simply to normal settling. For more on this topic, see our pages, Recognizing Damage and Counterarguments (CVDG Pro). Whether you have cosmetic or structural damage or both, you will need to document it as

extensively and as early as possible. For more on documenting damage, read our page Recording Damage.

Damage Repair and Costs

"Structural" and "cosmetic" are **not** synonyms for "expensive to repair" and "inexpensive to repair", respectively. A large amount of "cosmetic damage" can be more expensive to fix than limited structural damage. Since **the total damage loss governs your options and your course of action**, the size of the loss is the standard by which you should judge your damage and determine how you handle your claim. In one case, the repair cost for the "cosmetic" damage was nearly $70,000, plus the cost of completely moving out of the house while the repair was done (over $40,000), plus an additional $20,000 of move-related costs. In just about all jurisdictions, an owner is required to disclose any significant damage, even if repaired, to any potential buyer of the property. Most real estate people will tell you that **this disclosure requirement can result in a significant permanent loss of value of the property, even after repair, separate and apart from the damage itself.** For more on evaluating and repairing damage, see the CVDG page, Damage Repair.

Legitimate Claims

A vibration damage claim is **not a good way to "get rich"** or to get a few cosmetic drywall cracks fixed "for free". Although some construction companies will pay small claims fairly easily through their insurance, many will fight every aspect of even a legitimate claim, especially if it is large. If you have just noted a few (under 10 or so) hairline cracks, it's at least possible that they were present before the construction; you may not have seen them. It is highly likely that you will hear just that argument if you make a claim, whether or not it is accurate in your situation. It takes determination, knowledge, persistence and money to pursue a large damage claim, so it should not be undertaken lightly. That said, if you can provide evidence linking the construction to the damage and have sufficient damage to justify your time, effort and money in pursuing your claim, then doing so is a realistic option.

Questionable claims can be fought by construction companies by use of "pre-construction surveys". Such surveys are often required by contract. They can involve something as simple as a construction company employee driving or walking by recording video of the outside of the house prior to construction start. In other cases, the contractor will also seek permission to videotape the interior of your home before start of construction. Just as videotaping may be required prior to the start of construction, some contracts may require pre-construction vibration monitoring in the area of the construction, which gives an idea of the normal vibration levels caused by traffic and people. If such surveys are done, you will need to **get copies of them** to pursue your claim. For more on this and other pre-construction matters, see Pre-Construction.

What If I Have Damage?

If you believe you have construction-related damage, you must first **consider the extent of the damage and the progress of the job** at the time you note the damage. A few "cosmetic" cracks in drywall or plaster simply are not of enough significance to justify pursuing a claim, especially if you note them late in the project. If you notice substantial damage early in the project, your very first action must be to **immediately notify,**

preferably both verbally and in writing, both the construction contractor and the entity (often governmental) for which the contractor is doing the work. Notification gives them a chance to address your damage and make any changes necessary to avoid further damage to your home and others. It also helps protect your legal rights. Usually, the insurance carrier for the job will be called in immediately and you will be dealing with the insurer, rather than the contractor or sponsor of the work.

Often, the contractor or their insurance company will involve an attorney almost immediately. At that point, you will have to give serious consideration to how to pursue your claim, perhaps even getting your own attorney, if your damages will justify the expense. The CVDG also provides information on what to expect after you make your claim. If your claim goes to litigation, you will find help in the CVDG on dealing with that process.

You may believe that your home insurance will cover such damage automatically. There is a very good chance that you will be mistaken in that belief. Most home insurance policies carry exclusions for "ground movement". These can be invoked by the insurer, legitimately or not, for vibration damage cases, even though the majority opinion in the courts seems to be that such general ground movement exclusions only cover "natural", not man-made, earth movement sources. For more on this topic and related ones, see the Pursuing A Claim page in the CVDG.

Vibration Damage Claims and You

Your probability of success in resolving a vibration damage claim favorably, either by settlement or litigation, depends as much upon your attitudes and behavior as it depends on the facts of the damage and your ability to link it to construction operations (see Damage Causation in the CVDG Pro). You may be understandably angry and frustrated at the people that you feel have damaged your home and subjected you to everything that goes with that, through no fault whatsoever on your part. However, you must not allow yourself to make bad decisions motivated mostly by that anger, especially before you are represented by an attorney. Tips on how to handle your interactions with the opposing side are available on the CVDG Professional Edition page, Handling A Claim. If you get an attorney, seek counsel from him/her.


Report of Investigations 8507

Structure Response and Damage Produced by Ground Vibration From Surface Mine Blasting

By D. E. Siskind, M. S. Stagg, J. W. Kopp, and C. H. Dowding

UNITED STATES DEPARTMENT

Cecil D. Andrus, Secretary

BUREAU OF MINES

Lindsay D. Norman, Director

It is virtually a given that opponents whose relative strength in negotiations is, or appears to be, far apart will be unlikely to reach a **fair** settlement. Since contractors have lawyers, money and experience on their side, a homeowner must do everything to reduce this disparity in perceived, or real, power to achieve a settlement. The stronger the homeowner appears, both in personal strength and detailed knowledge of the scientific and case facts, the better and more likely a resolution prior to a trial. The homeowner should have some real knowledge of the contents of the CVDG, preferably the Professional Edition, as this will provide the scientific basis for his arguments. Of course, there are other ways to gain some of that information (e.g. USBM RI 8507 shown at right), but the CVDG is probably the most concentrated source of information about handling construction-related vibration damage claims available. The

CVDG Professional Edition section, Settlement, has detailed information to help the homeowner prepare for settlement talks.

Where Do I Go Now?

Other topics discussed in the *CVDG* can be located in the CDVG Contents and in the links along the margins of the pages. To give yourself maximum flexibility to view the *CVDG* web pages, you may want to open the CDVG Contents in a separate window or tab. You can get a **free, non-business use copy of the entire CVDG, minus ads and web navigation,** in PDF format from our Downloads page. If you have just noted damage in your home, you will probably want to start with the CVDG sections Vibration Potential, Recognizing Damage, Recording Damage and Pursuing a Claim. If construction is scheduled near your home, but hasn't taken place, take a look at Pre-Construction for steps you can take to safeguard your home and document its condition prior to construction. Whether damage has been seen or not, you will need as much documentation as you can get, in the event of damage.[1]

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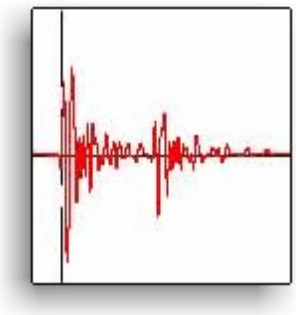
1. Most of the pages of the CVDG have footnotes, like this one, which provide either short-form references to vibration scientific literature or additional information. Full citation information can be found on the Cited Literature page. These citations are provided to allow those having limited or no familiarity with the vibration damage literature to read it and draw their own conclusions.

Vibration 101



Every one of us experiences vibrations constantly. If we are not hearing-impaired, the sounds we hear are vibrations in air. The waves in a pool, lake or the ocean are vibrations in water. We all feel that we understand what the term "vibration" means, because we are so familiar with various forms of it. However, many people may not be aware of what vibration means in the technical sense, especially when it comes to ground vibrations. Because an understanding of vibration in that sense is important for what comes after in the CVDG, we will undertake on this page to provide some definitions and examples that provide a better, though mostly non-technical, understanding of the properties of ground vibration.

Vibration in Physics

A vibration in the scientific sense is a passage of energy that causes oscillations (movements) about an average position in the particles or molecules which make up the material. Low intensity vibration passages produce no permanent change in the position of particles making up the vibrating material. A vibration must travel in some physical material. In that respect, it differs from visible light and other forms of **electromagnetic radiation** (X-rays, radio, ultraviolet, etc.), which can move through total vacuum.

Introductory physics often talks about **ideal materials** in which vibrations, once started, persist indefinitely. Vibrations in **real materials** eventually fade away due to damping effects, which ultimately convert the vibration energy to heat. You can show the effect of damping just by tapping a glass; initially the sound is relatively loud, but dies away quickly because the energy of the vibration is lost mostly to creating the sound you hear when you tap the glass. Some of that energy also goes into producing a very slight temperature increase in the glass itself. This is the reason that articles that undergo continuous vibration become warm or even hot. The repeated vibrations impart more and more energy to them, which appears as heat (a faster and more disordered movement in the molecules of a substance). The conversion of the motional energy of vibration to the disordered energy of heat is an example of the operation of the famous Second Law of Thermodynamics, which says that entropy (a measure of disorder in a system) tends to increase over time.

Vibrations and Waves

The vibration of water to form waves shows one of the prime properties of vibrations, that they move as repeated **displacements** (i.e. changes in position) in the particles or molecules which compose the material. Waves in water are relatively simple, in part because water is pretty much the same everywhere in the local "neighborhood" and has relatively low damping. We can see waves on water, but visualizing vibrations in other materials requires specialized equipment (e.g. a microphone and an oscilloscope for

sound, a seismograph for ground vibration).

In real-world materials, vibration waves often look different, both in shape and intensity, along the three different directions (up-down, back-forth, side-side). Scientific instruments are designed to record the vibrations in all three perpendicular dimensions at the same time. These differences are also important from the damage standpoint; vibrations in the side-side ("**transverse**") and back-forth ("**longitudinal**", sometimes seen as "**radial**") directions cause potentially damaging **shear** (differential directions or speeds of movement) within structures. The up-down ("**vertical**") movement is usually less damaging, because structures are built to withstand vertical forces.

Simple waves can be characterized by something called the "**frequency**", usually quoted in **Hertz** (Hz). It is just **the number of wave peaks passing a given point per second**. Waves with higher frequencies carry more energy per unit of time than those with lower frequencies. Most vibration waves are not comprised of a single frequency. They can be analyzed mathematically to reveal that they have multiple "**frequency components**", which sum together to produce the complex wave observed. The frequency components of a given complex wave can be extracted from the shape of the wave using a minicomputer running a "**Fast Fourier Transform**" program. More information on vibration frequencies and how they are determined from seismograph data are found on the page, Vibration Frequencies.

Vibration components with different frequencies travel differently in materials, leading to changes in the overall vibration shape and frequency distribution with distance. If you have a stereo, you know that the deep bass notes (low frequency) travel further than the high notes (high frequency). The same thing happens in ground vibration. Unlike your stereo, the **ground vibration frequencies of most concern and interest are not those that can be heard; they are more felt than heard**. Typically, construction vibrations have components which range in frequency from about 100 Hz down to below 10 Hz. **Ground vibration frequencies below 40 Hz are the ones of most concern in causing damage**.

Sound vibrations and ground vibrations are typically very complex in their wave structure, being comprised of multiple components of different frequencies. But, they still look like waves, albeit seemingly irregular ones, when visualized with the proper equipment (see the illustration above for a seismograph trace of the wave structure of a single short ground vibration caused by impact on the ground). A more detailed description of vibration phenomena can be found in almost any college-level physics text.[3]

Ground Vibration

Ground vibration can be either natural (earthquakes) or man-made (blasting, construction, equipment, etc.) in source. In both cases, **seismographs** (see blasting seismograph example at left) are used to record the ground vibration. To accomplish this meaningfully, seismograph detectors must be firmly anchored to the ground (i.e. they must achieve good "**ground coupling**") so that, as the ground moves, the detector moves in exactly the same way. **Without proper ground coupling, seismograph data are meaningless.**

Seismographs for earthquake measurement are somewhat different from those used for man-made ground vibration measurements like the blasting seismograph above. In part, this is because they must be able to measure a **far** greater range of ground vibration intensities than those produced by human activities. This is the reason that the "**Richter Scale**", used to describe the intensity of earthquakes, is both "open-ended" (i.e. having no upper limit) and exponential, meaning that every unit increase in Richter intensity indicates an energy involved which is ten times greater than the next lower one. You can learn more about ground vibration measurement and scales in the CVDG section, Vibration Measures (available only in PDF versions). In spite of their design differences, the purpose for both kinds of seismographs is the same - to provide a reliable record of ground movement.

Unlike the "ideal" vibrations discussed above, which involve movement of particles or molecules back and forth about one unchanged position, both earthquake vibrations and some man-made ones can produce **permanent** changes in the relative positions of "particles" comprising structures. Since these permanent changes are essentially always unwanted, we refer to them as **damage**. In earthquakes, such damage can be seen as cracks in the ground and, in a large earthquake, collapsed buildings and infrastructure. **The larger the vibration, the greater is the potential for these permanent changes in particle positions**.

Vibration and Distance

In materials like water, which are the same pretty much everywhere (i.e. "**isotropic**", "**homogeneous**"), the vibration intensity decreases with distance approximately according to the same "$1/r^2$" law that Newton found for light intensity with distance from the source. The reason for this is fundamentally geometric. As a given amount of energy spreads out from a source, it passes through a "sphere" of continually increasing size whose surface area increases proportional to the radius squared (r^2) and, over which, the energy spreads. Note that the vibration energy spreads in all directions, even though it does not spread equally in all directions, unless the transmission is through a single isotropic material. However, most materials, especially the ground, are anything but isotropic.

Different types of rock and soil transmit vibrations differently, in intensity, frequency, and speed. Clay soils, because of their greater coherence, transmit vibration more efficiently than sandy or loamy soils. Even soils with different amounts of moisture can behave differently in vibration transmission. Differences in vibration transmission and reflection in rock are pretty well-understood by geologists, particularly those at oil companies. They use such differences in a geophysical technique called "seismic profiling" to reveal underlying rock structures and search for possible oil deposits. The result of all these and other transmission differences is that ground vibration intensities usually don't follow the "$1/r^2$" law with any exactness, even though vibrations generally decrease in intensity with distance from the source.

Being at a greater distance from a vibration source can't always be seen as much comfort, if your home is close enough to hear the vibration source. Indeed, it is well-known that some types of **lesser vibrations at a greater distance can be more damaging than those closer in**. This is due to a well-documented lowering of the ground vibration frequency with distance; these lower frequency vibrations often have special

interactions (called "**resonances**") with the house structure that other, higher frequency, vibrations lack.

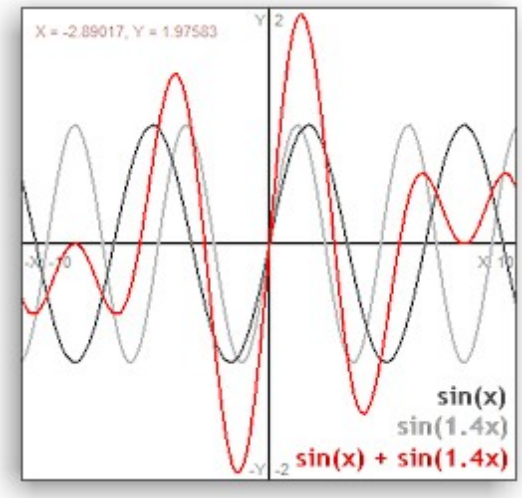
Wave Propagation and Interference

Ground vibrations can take multiple paths from the source of the vibration to a house or a seismograph. These paths can be divided into two basic groups. Some vibration waves travel along the surface. There are several different types of **surface waves** ("**Rayleigh waves**", "**Love waves**", among others) which differ in the specific pattern of particle movement with respect to the overall direction of movement ("**propagation**") of the wave. Others travel through soil or rock ("**body waves**"). Body waves can move as surface waves, if they reflect off underlying ground structures and reach the surface. The different paths lead to different arrival times for the vibration waves and different shapes for the two different components. Since the foundations of homes are, for all intents and purposes, at the surface of the ground, surface waves are of most interest in interacting with homes to cause damage.

Vibration records often show two seemingly separate waves from the same source event arriving a fraction of a second apart, if the source vibration is sufficiently short that the two types of waves don't overlap. The graphic at the top of this page is a good illustration of that phenomenon. It was caused by a sharp impact, producing an initial vibration lasting a bit over 0.1 second; that dies out and is replaced by a second wave of similar shape but lower intensity about 0.15 second after the beginning of the first.

Vibrations can also be reflected from some underlying soil or rock layers, creating **interference** patterns with later, slower moving, incoming parts of the vibrations. Interference can be easily seen in water as waves reach the shore and reflect back onto the incoming waves, producing a more "jumbled" pattern of waves. In this and all other forms of wave movement, wave peaks and valleys in multiple waves interact to produce a larger or smaller sum wave, depending on whether wave peaks coincide with wave peaks ("**constructive interference**") or wave peaks coincide with wave valleys ("**destructive interference**").

The graphic at right shows the interference effects of summing two mathematical sine waves of different peak-to-peak distances (frequencies). For some values of x, the red sum wave has a value of zero, because the positive and negative peaks of the two components (sin(x) and sin(1.4x)) cancel each other, due to destructive interference. For other values, the red sum wave is much larger than either simple wave, due to constructive interference. One of the results of interference effects from vibration waves taking different pathways in ground vibration is that **two houses at the same distance from the vibration source can experience very different vibration intensities and histories**.



Causes of Man-made Vibration

Most people know that vibration can be produced in many different ways and transmitted through all kinds of different materials. However, most kinds of man-made vibrations, including those caused by people walking on floors in a house, are too small in intensity, last for too short a time and/or affect too little an area to be of much concern in causing damage to a structure. From the standpoint of damage to structures, there are only **three important sources of man-made vibration: blasting, operation of heavy equipment and, in some extreme cases, traffic and other transportation**.

Much of the scientific literature of vibration effects is based on mine blasting, because such damage effects were recognized earlier in mining than in construction. The mining vibration studies provide much useful information on vibration effects, even though they are not directly useful in estimating likelihood of damage from construction activities. **Vibrations from construction operations are increasingly being recognized as causes of damage to homes and other structures**. In many ways, **they are more worrisome than blasting, because of their much longer vibration durations and lower frequency compositions**, magnifying resonance and fatigue effects in a house.

Ground Vibration and Homes

Damage to homes from ground vibration can occur by **three basic types of interaction**. The first is the **direct interaction of the ground vibration with the house, without any of the resonant interactions** mentioned above. If a vibration is large enough, it can do damage even though its frequency composition does not excite directly the natural vibration frequencies of the house (**"resonant frequencies"**). The second type of interaction with ground vibration is that of **ground vibrations with frequencies which overlap the vibration frequencies of the home**, i.e. those which are "**in resonance**" with the home. Such **resonant interactions are self-reinforcing and, therefore, particularly damaging, if the vibrations are large enough and last long enough**. Resonance effects are discussed in more detail on the CVDG page, Resonance/Fatigue. Finally, the **ground vibration can cause damage by bringing about settling of the soil around the home, with corresponding settling of the house foundation**. Ground settling effects are often indicated by cracks in the soil around the home, with possible damage to home support structures (slabs, foundations).

Mitigating Vibration

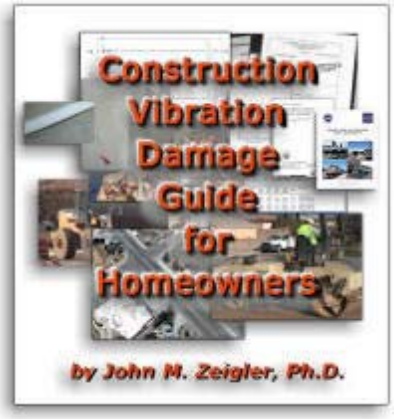
Hard materials like rock, or to a somewhat lesser extent, a home, transmit passing vibrations well. If the vibration is sufficiently large or continues long enough, they will be damaged, since all real materials possess limited strengths. One can decrease ("mitigate") vibration transmission and buildup, usually by directing the vibration to a flexible material which can move without damage, and thereby, convert the vibration energy to movement and, ultimately, to heat. There are many examples of this approach in our everyday world.

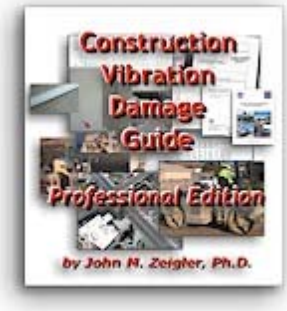
Many cars use shock absorbers of various sorts filled with gas or liquid. Vibrations from the wheels are transmitted into the shock absorber, where most of the intensity is absorbed in the movement of the fill material. Most car engines are mounted on large blocks of special rubber, which move slightly while the engine is running, absorbing the engine vibrations. These approaches are also used, to some degree, in earthquake-proofing large buildings in earthquake-prone zones, albeit on a huge scale.

Since rock is a good vibration transmitter, a different approach is used in mine blasting to reduce vibrations. Most mines and quarries use small, specifically-patterned, multiple explosive charges to break the rock first, then a second set of charges a few thousandths of a second later to heave the broken rock away from the mine face, where it can be loaded and transported. Since the rock is already broken, the cracks absorb a good deal of the vibration of the second blast. These multiple small blasts occurring within a small fraction of a second are known collectively as a "**shot**" in the mining industry. U. S. Bureau of Mines publications have specific instructions for mitigation of mining blast vibration, and, by implication, those from construction-related blasting.[2,5]

Non-blasting construction vibration can be decreased mostly through the use of the correct equipment in the correct way. The Federal Transit Administration's Noise and Vibration Manual provides a list of steps to be taken and procedures to be avoided in mitigating construction vibration.[1] Vibration mitigation in construction settings is further discussed on the CVDG Pro page, Mitigating Vibration. Mitigation techniques are well understood and publicly available for free over the Internet to any contractor. This situation creates a moral, if not contractual and legal, obligation to mitigate vibration, especially from those operations known to be of concern in vibration damage (blasting, pile driving, vibratory compaction, impacts generally).

The CVDG





I hope that this short tutorial on vibration will help you in reading and using to best effect the rest of the CVDG, in either the free Edition for Homeowners, available in part online or in full in a free downloadable PDF file, or the much more extensive Professional Edition. Although a full scientific understanding of vibration and its effects can be quite involved, the basic concepts are within the understanding of most people. If you have construction-caused vibration damage or are concerned about that possibility, the CVDG will help you understand the issues, evaluate your position and deal with those who may have caused the damage.[4]

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1. **Federal Transit Administration's** *Noise and Vibration Manual,* p. 12-12 - 12-13
2. OSMRE Blasting Guidance Manual, pp. 43-44
3. E.g., *Fundamentals of Physics*, D Halliday and R. Resnick, John Wiley & Sons, 1970
4. Many of the pages of the CVDG have footnotes, like the ones on this page, which provide short-form references to scientific literature on various vibration topics or additional information. Full citation information can be found on the Cited Literature page.
5. USBM IC 8925, p. 80, *et seq*.

Is Damage Possible?

Anyone searching the Internet for information on construction vibration damage will find numerous sites of vibration monitoring firms and consultants. Many of these say, in essence, that "damage can't happen" in construction. Unfortunately, these views may not be entirely unbiased and free of conflict of interest, since such **vibration monitoring firms and consultants do virtually all their work for construction contractors**. The goal of this page is to place construction damage, and representations about it, in a more complete scientific context. On this page, I'll try to give you some sense of whether these claims can be taken literally or *cum magno grano salis* (with a very large grain of salt). Many of the topics here are discussed with greater detail in later pages of the CVDG.

Vibration Damage and its Causes

Although structural damage associated with construction can, and does, occur, many times the apparent construction damage is seen as "cosmetic" cracking in drywall or plaster and exterior surfaces such as stucco. Since such damage can also be caused, at least in principle, by **settling, thermal cycling (i.e. temperature changes) and normal aging**, a few hairline cracks (under 10) in a house after construction is not necessarily indicative of construction vibration causation. Similarly, the vibration literature recognizes repeatedly that people are more sensitive to vibration perception than structures are to vibration damage. Another way of saying this is that **perceived vibrations in a home may not cause damage**. Finally, once people find cracking, they may begin to look more carefully for hairline cracking and other forms of damage that they might otherwise have failed to notice. Thus, simply **becoming aware of such cracks or other damage during construction is not necessarily indicative of construction causation**, *per se*. Indeed, all these arguments are often offered as damage rationalizations (CVDG Pro) by contractors and their experts.

That said, **the experience of watching cracks form as a construction crew used a large excavator bucket to break asphalt pavement by pounding on it** (see video frame capture at right) in front of my home convinced me that construction vibration damage is real.[9] I found damage of similar sorts in every home on my street which I examined. Other residents all along the street reported similar use of pounding with an excavator to demolish pavement. These facts, and many others, strengthened my views both that the construction was responsible and that construction damage is more common than some might think.

The Construction Position

Like many others all over the world, I was told by the construction firm management, its employees, its "experts", and the employees of the municipality sponsoring the work that "construction can't cause damage". **Several of those who made these statements refused outright multiple invitations to view either the damage or video of the damage being done, indicating a position entirely based on bias.** Even the many construction or construction-allied workers in a trial jury pool repeatedly made prejudicial statements in front of the other prospective jurors to the effect that "damage can't happen" in construction. None of these construction people offered any scientific evidence whatsoever supporting that view, nor did they have any significant scientific background themselves, which might have helped and qualified them to champion such a clear-cut position.

Worse yet, the views of those who are involved in the construction field are so strong on this subject that it could reasonably be asked if **such unsupported opinions might be contributory to the kind of reckless behavior that I saw and videotaped on multiple occasions**, which directly violated the operator's manual instructions in multiple places for the types of heavy equipment used. Of course, that behavior also seriously damaged large numbers of homes. Because I'm a scientist by training and inclination, I decided to look into these assertions on a broader scale, in the hope of finding some valid scientific basis for them, or, at least, of understanding their source.


Report of Investigations 8507

Structure Response and Damage Produced by Ground Vibration From Surface Mine Blasting

By D. E. Siskind, M. S. Stagg, J. W. Kopp, and C. H. Dowding

UNITED STATES DEPARTMENT
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BUREAU OF MINES
Lindsay D. Norman, Director

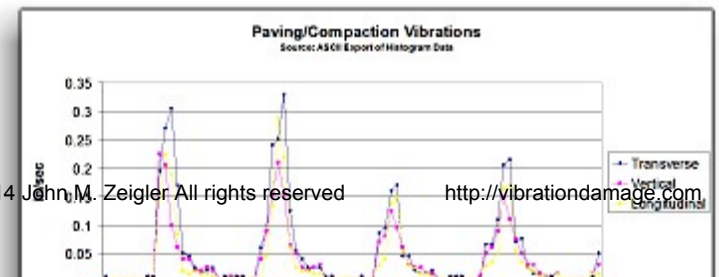
US Department of Interior
Office of Surface Mining
Reclamation and Enforcement

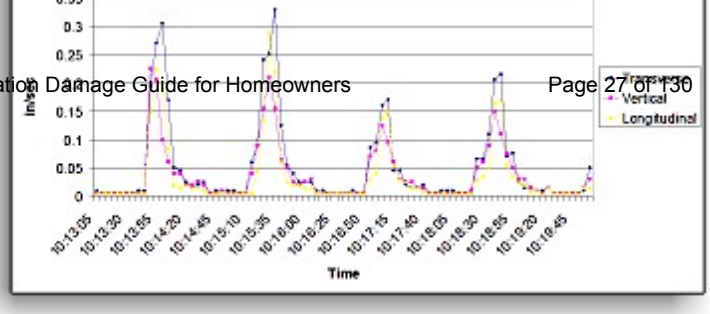
The Vibration Damage Literature

Much of the scientific and technical literature on vibration damage, and many of the vibration standards, are **based on studies of damage due to vibrations from surface mine and quarry blasting**. One commonly used vibration standard in the U.S., the **Office of Surface Mining (OSM) standard** is founded largely on the recommendations of the highly respected **U.S. Bureau of Mines Report of Investigations 8507** (**USBM RI 8507**) study. While the OSM standard doesn't entirely conform to all the recommendations of USBM RI 8507, it is widely cited not only in mining, but construction settings, perhaps because it sets very high limits on allowable vibrations. Thus, **claims in the literature, in state and municipality regulations, and on the Internet about the "impossibility" of construction damage are often largely or entirely based on the OSM blasting standard**. As discussed in USBM RI 8507, there has been a steady downward trend in blasting vibration intensities adjudged as "non-damaging" and "allowable", as more research has been done.[1] You can find links to download free copies of these and other standards and studies on our More Information page.

Mine Blasting vs. Construction Vibration

Surface mine blasting vibrations occur infrequently (perhaps a few times per week at most) and produce vibrations which last, at most, only a



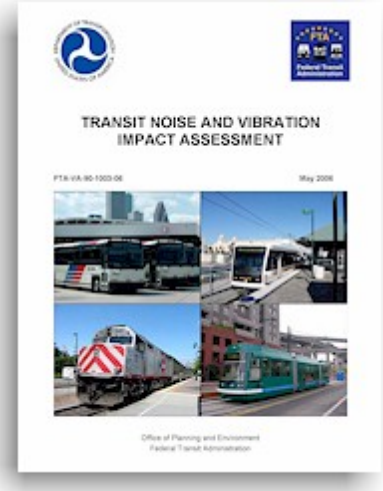


few seconds. Construction vibration, on the other hand, can persist for minutes, hours, days or even months. As can been seen in the diagram, the paving vibrations (largely from vibratory compactors) from a real-life road reconstruction project remain over FTA standards for about a minute at a time in this example. There are four such episodes in just the 6 minute period shown in the diagram, of more than an hour of such vibrations in this one pass, of several. The seismograph was located approximately 5 feet from the closest approach in this first layer paving pass over compacted soil.[8] Some vibrations recorded on the project lasted as long, were twice the intensity shown here and were repeated some 20 times in front of one home on one day, again, of several.

This difference in duration and number of occurrences between mine blasting and construction vibrations is critical, since long-lasting vibrations can bring into play both fatigue and resonance effects, which are of far less importance in short-lived, infrequently repeated blasting vibrations. Indeed, USBM RI 8507 indicates this limitation of blasting studies explicitly:

> *"Safe vibration levels for blasting are given in Table 13, being defined as levels unlikely to produce interior cracking or other damage in residences. Implicit in these values are assumptions that the structures are sited on a firm foundation, do not exceed 2 stories, and have the dimensions of typical residences, and that the vibration wavetrains are not longer than a few seconds."*[2] *(emphasis added)*

Thus, **use of blasting standards in construction settings is scientifically and technically questionable at best**. Use of the OSM vibration standard, on which so many of the "damage can't happen" assertions are based, is clearly unsupportable in construction vibration damage evaluations. Its basis is the recommendations of USBM RI 8507, which specifically disclaims applicability in a setting with semi-continuous vibrations of long duration. There are **other, far more stringent, standards for construction vibration**, which recognize this fundamental difference, perhaps most notably the one in the Federal Transit Administration's *Noise and Vibration Manual* (at right). **The fact that construction vibration standards set far more stringent limits for "allowable" vibrations than those imposed for blasting settings is, by itself, strongly indicative that "construction can't cause damage" arguments are insupportable, scientifically and, perhaps, legally.**



Heavy Equipment Concerns

Although mining vibration standards are inappropriately employed for setting allowable construction vibrations, even those lenient standards can be violated by some construction operations. In particular, **pile drivers are known to produce vibrations in excess of the OSM blasting standard**.[3] Widely used

vibratory compactors, like the one at left, often exceed some or all of the FTA standards, as shown above. Indeed, the FTA specifically advises against their use, "Avoid vibratory rollers and packers near sensitive areas."[4] Thus, any use of these kinds of equipment in populated areas should be viewed with concern for the vibration they produce.

Another concern, with limited investigation in the vibration damage literature, is the **vibration caused by driving tracked heavy equipment** over significant distances in populated areas. Vibrations produced by driving tracked equipment have frequencies in the sub-40 Hz range of most concern for damage effects. They produce accelerations higher than those produced by vibratory compactors and can last for a minute or more. This is more than long enough for the self-reinforcing effects of resonance to manifest themselves in home damage. For more on this topic, see the CVDG Pro page, Vibration Signatures and the CVDG page, Vibration Potential.

Science and Opinion

Not every construction job causes vibration damage, even if vibration is felt and makes nearby residents feel uncomfortable. However, some construction jobs do result in damage, in most cases, predictably so. In my experience, damage usually occurs because the contractor has violated equipment use instructions, used the wrong equipment in the wrong areas, didn't understand or didn't care about applying **relevant** vibration standards, or was given poor quality vibration data or poor advice about it (or some combination thereof). **Scientifically valid conclusions must be based on reliable and complete data, thoughtfully, properly and fully interpreted**, not pre-conceived or pre-ordained opinions, which, in some documented cases, ignore the contradicting data entirely.

Blanket statements to the effect that "construction vibration damage can't happen" should be viewed with inherent skepticism, in the absence of reliable scientific data and properly applied vibration standards supporting those statements**.** While people are entitled to their opinions, unsupported opinions cannot, and should not, be taken or presented as scientific or practical fact - especially when they fly in the face of extensive scientific evidence contradicting the basis of such opinions. Even representations of large amounts of "experience" with construction vibration damage evaluation do not, by themselves, prove that damage can't happen in a given set of construction circumstances. If anything, **such poorly supported, pre-conceived opinions prove more about the mindset of the speaker than about construction vibration damage potential**.

Construction Vibration Damage Prevalence

It is increasingly acknowledged that vibration damage from construction is of concern[7]. A search of the Internet for "construction vibration damage claims filed" will turn up references to hundreds of such claims at any given time. Even if some of these are invalid or, at least, cannot be tied conclusively to construction work, no reasonable, knowledgeable person would argue that so many examples support the notion that "construction can't cause damage".

While there are no readily

accessible statistics on the actual prevalence of construction vibration damage, either in the U.S. or the world as a whole, over half of those downloading the complete PDF version of the CVDG from Vibrationdamage.com cite "Damage to home" or "Damage to building" as the reason for their interest in it. Although these self-reported reasons do not constitute a scientifically designed prevalence study, their sheer numbers and worldwide distribution (see map graphic above - warmer pin colors (reds, yellows) represent more reports) suggest that construction vibration damage is a problem deserving of acknowledgement, concern and better, more directly relevant scientific study.

Should I Pursue a Damage Claim?

It has long been recognized that vibration damage can inflict an unreasonable burden on homeowners.[5] You (and your attorney, if one is involved) should not let statements on the Internet, representations by contractors, their employees or their insurers, or even those here in the CVDG, decide whether you pursue a claim. Instead, that decision should include, at a minimum, considerations of:

- the nature and number of post-construction damage sites (e.g. over 600 in the author's case),
- your ability to link the damage to specific construction procedures or actions, preferably at specific documented times
- whether you can provide evidence of similar damage to other nearby structures,
- the dollar amount for the repair of your construction-related damage,
- your ability to finance litigation, if it becomes necessary,
- your own willingness to commit the time and put up with the hassle of pursuing a legitimate claim.

You may feel that you can have an attorney send a damage claim letter to the contractor and get a fairly quick settlement payment. That may happen in some instances involving relatively minor damage, but the biases of many of those in the construction industry, as well as their personal financial interests (e.g. future insurability and cost thereof), work against that outcome. It is much more likely that you will have to pursue the claim at some length to have any chance at getting reimbursement for your damage. That will almost always entail the involvement of an attorney at some point.

Whatever course you settle upon, it should be based on a careful analysis of the facts which you can prove, not on the uncritical, unsupported assertions of those who may not understand (or want to understand) the science of vibration damage, as applied in your situation, or those who may have a conflict-of-interest in rendering an unbiased opinion about construction vibration damage.

1. USBM RI 8507, p. 3
2. USBM RI 8507, p. 58
3. Federal Transit Administration's Noise and Vibration Manual, pp. 12-12 - 12-13
4. Federal Transit Administration's Noise and Vibration Manual, p. 12-14
5. "*At the same time, environmental control agencies responsible for blasting and explosives need reasonable, appropriate, and technologically established and supportable criteria on which to base their regulations. Finally, neighbors around the mining operations and other blasting, as shown in figure 1, require protection of their property and health so that they do not bear an unreasonable personal cost.*" USBM RI 8507, p. 4
6. GROUND VIBRATIONS CAUSED BY ROAD CONSTRUCTION OPERATIONS, D J Martin, Department of the Environment, Department of Transport TRRL Supplementary Report 328: Crowthorne, 1977
7. "*Harmful vibration effects of construction activities occur frequently. This is a field of growing concern*." M. R. Svinkin, Practice Periodical On Structural Design and Construction, Vol. 9, No.2, May 1, 2004, ASCE, p. 108
8. Specific distances between seismographs and construction activities in the CVDG are taken from my video of them, as the vibration technician **never** recorded the locations of the seismographs and construction work location and type with anything like enough specificity to identify them. Typically, they included only a street address and, often, an inaccurate indication of the type of construction activity involved.
9. The danger of even properly-done pavement breaking operations was known at the time this damage from improper procedures was done: "*However, if vibration concerns involve pavement breaking, extensive pile driving, or trains, 7.5 m (25 ft) or less from normal residences, buildings, or unreinforced structures, damage is a real possibility. This may also be true if these operations occur within 15 m – 30 m (50 ft- 100 ft) from historical buildings, buildings in poor condition, or buildings previously damaged in earthquakes.*" *(Transportation- and construction-induced vibration guidance manual.* June 2004. California Department of Transportation, p. 17).

Pre-Construction

To the extent possible, the safest approach to impending construction is to try to avert any possible damage before it occurs. This is far less time-consuming and expensive than it is to get damage reimbursed and carry out the repair. This page gives some tips about how you might get ready for significant construction planned in your area.

Pre-Construction Documentation of Your Home

If you are aware of planned construction in your area, i.e. within about 500 yards of your home, take an hour or so and document on video the pre-construction condition of every room in your house, the exterior and any other structures on the property. Narrate the video with the facts of the locations seen and whatever other information you believe is important. If you don't have a video camera and can't easily borrow or rent one, photos can also be used for this purpose, though you will have to have an accompanying written log detailing the locations of the photos, etc. If damage occurs, these records will **greatly** strengthen your claim that the construction is responsible for it. Such a record can also have the side benefit that you will also be providing **evidence of the contents of the house** in case of a fire or other insured loss. Just make sure you **videotape or photograph the walls, door frames and other elements of the house structure while you are also recording the contents**. Once you have recorded the condition, transfer it to DVD (if possible) and place the DVD and the original tape or photographs in a safe place outside the home, where you can get to it in time of need.

Web Site Project Information

Many infrastructure projects (roads, water mains, etc.) are funded by governmental entities (towns, cities, states, Federal government). These days, virtually all such projects are announced in some form on the web site of the sponsor. Such announcements may take the form of Requests for Proposals (RFP's), public comment meeting announcements, minutes of governing body meetings and others. You can often find what you're looking for fairly quickly just by searching the site for the name of your street and nearby streets. When you become aware of work ongoing or planned in your area, one of the first things you should do is **visit the web site and find out everything you can about the project** as it is intended to be done. **Print the pages so that you have a permanent record**, making sure that the printed pages show at least the URL of the pages being printed and the date printed.

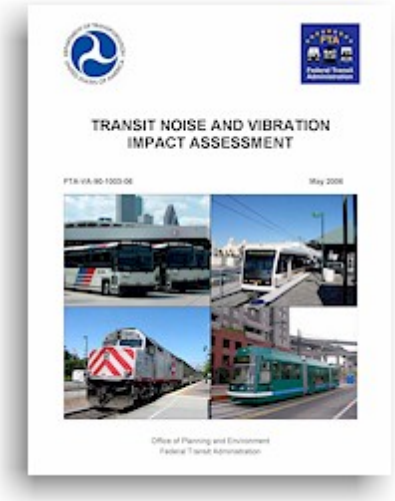
Information which you may need from the site includes: a copy of the RFP and/or contract for the work (if available online), planned time of the project, traffic control measures intended, expected notifications of nearby residents of interruptions in water and other services, dates and times of public comment meetings, source of the funding for the project (state, local or Federal) and just about anything else you can find. The

contractor may cite the availability of this information, but will be less thrilled to talk about any examples where it violated the rules and plans laid out on the site. If the contractor has a web site, you should find and check this out, as well. If either web site has a comment section about the project, make **factual** comments about your concerns and keep a hard copy of your comments.

Pre-Construction Meetings

Most governmentally-supported construction projects are announced in advance. The public is often given a chance to comment about the upcoming work, both in writing and orally in meetings prior to start of work. Of course, you will not know in advance if you will have damage, but you would be well-advised to attend such meetings, voice concerns and ask questions related to the vibration potential of proposed work. These meetings are announced in the legal section of the newspaper and may also be publicized by flyers or on the web site of the sponsoring entity.

Such public meetings may be **videotaped**; if so, make a note of it. If not, and you have specific concerns, you may want to do so yourself, unless forbidden to do so. Take **written notes** of the names and topics discussed by every speaker or questioner, unless you are video or audio taping the meeting.



In such a meeting, one would want to ask if any blasting was to be done, or if vibratory compactors, pile drivers or other equipment with significant vibration potential were intended for use in the project. The FTA *Noise and Vibration Manual* indicates that such activities could be problematic in "sensitive areas".[1] If you have an older house with plaster on lath walls, a historic home or any other concerns about **vibration sensitivity**, you should voice such concerns at public comment meetings. You could download a copy of and take with you the FTA *Noise and Vibration Manual* to bolster any objections you may have.

It would also be wise to ask if any ground **vibration monitoring** is to be done in connection with the project, either prior to or during the construction. If there is no monitoring expected, ask why not. If monitoring is being done, find out when, where, by whom, and to what purpose. Your goal here is to ascertain whether any such monitoring will be done meaningfully and correctly and whether the information gained will be made accessible to the public.

You should inquire about what kind of "**pre-construction surveys**" are required or expected as part of the contract. If interior video or photos of residences are expected, make sure you take some control over the visit parameters and that you get copies of the video and/or photos generated. See our Conditions Documents (CVDG Pro) page for some example documents you can use to control such visits.

If you are particularly concerned, it would be desirable to spend a little time on the Internet digging around to find out what you can about the contractor's record, and, if it has **worrisome aspects (lawsuits, records of complaints, etc.)**, bring copies and broach the subject at the comment meeting. You might also want to find out how much

insurance coverage the contractor is carrying for the job and the contact name and number at the insurer for the contractor.

Also ascertain the **responsible person** at the sponsor for the upcoming work. The goal here is not to find out how to file a claim, but to determine who to contact in the event of problems. If there are problems, you will not want to spend hours on hold waiting for someone willing to admit some responsibility. Get contact numbers and names. Find out what the process is for making any complaints or comments about the work after it starts.

Another important aspect is to learn how the sponsor intends to supervise the work. Will there be an occasional "look-see" or will someone representing the sponsor visit the site(s) on an everyday basis? The better the **supervision**, the more likely it is that things will be done correctly, without damage. Note that there is no guarantee that, no matter how many concerns you raise, the sponsor will pay any attention to them. However, your position will be strengthened immensely in a damage situation, if you have a record of having voiced concerns/objections at public comment meetings.


This document has important legal consequences; consultation with an attorney is encouraged with respect to its use or modification. This document should be adapted to the particular circumstances of the contemplated Project and the controlling Laws and Regulations.

STANDARD GENERAL CONDITIONS OF THE CONSTRUCTION CONTRACT

Prepared by

ENGINEERS JOINT CONTRACT DOCUMENTS COMMITTEE

and

Issued and Published Jointly by

ACEC

ASCE American Society of Civil Engineers

National Society of Professional Engineers

AMERICAN COUNCIL OF ENGINEERING COMPANIES

ASSOCIATED GENERAL CONTRACTORS OF AMERICA

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To the extent possible, you will also want to ask about the **requirements of the construction contract**, including expected dates and times of work, whether work will be done on weekends, etc. In most cases, the construction contract will already have been let; the winning contractor bidder may be represented at the meeting. While individual entities will have their own contract provisions, many will incorporate by reference the *Standard General Conditions of the Construction Contract of the Engineers Joint Contract Documents Committee*. This is a widely used boilerplate document which has many provisions and lays out many responsibilities for the contractor, including ones for adjacent property protection. You have to pay to get a copy, but, because so many contracts incorporate it, you can usually find a copy for free on the Internet as part of a published contract, if you search for it by name. It would be useful to know if this has been made a part of the contract for the proposed construction; if so, you should get a copy of the whole contract, including addenda and attachments.

Proper Perspective

Keep in mind as you ask your questions that no damage has been done to you or your property yet and none may ever be done. Make sure your tone is friendly and non-challenging, even if you have to be persistent in getting your questions answered. Make it clear that you are just trying to understand what will be done and what consequences can be expected from the work. Chances are that the contractor and the sponsoring entity are simply trying to do a professional and timely job, while taking into

account the rights and comfort of homeowners.

Of course, once construction starts, your hard work in getting your questions answered may come to nothing. The contractor might be determined to cut corners, ignoring the people affected by the work. At the very least, you will have documented things in case you have to get work stopped or moved - or if something more serious happens.

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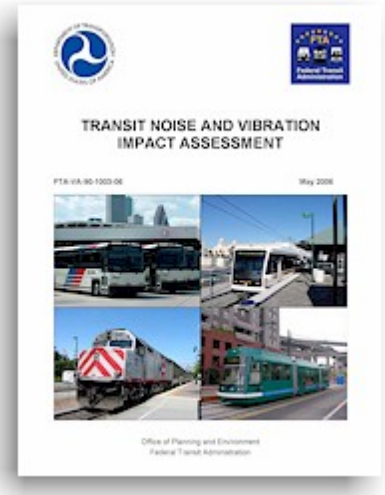
1. **Federal Transit Administration's** *Noise and Vibration Manual*, p. 12-12 - 12-13

Vibration Potential

Most construction procedures create vibrations which can be felt, if one is sufficiently close. However, not all are of equal concern. **Felt vibrations will not always cause damage**. On this page, I summarize some typical construction operations, with comments, based both on my road construction experience and the literature of vibration damage, on their potential for causing vibration damage. Since other kinds of construction involve many similar uses of the same types of construction heavy equipment, one can apply this information in other types of construction using the same types of heavy equipment.



Construction Operations and Vibration Potential

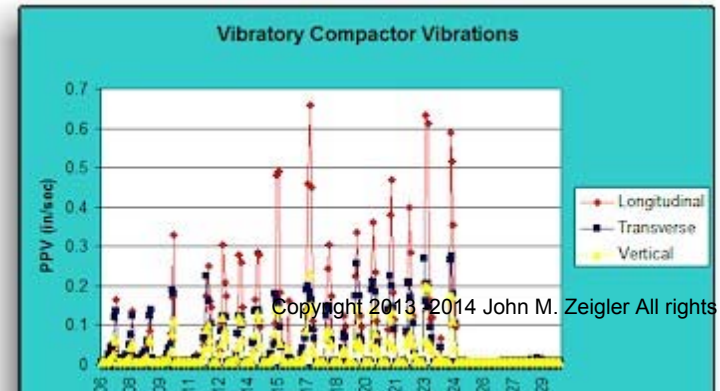
Those operations of the most concern are **bolded in the list below**. I try to differentiate those operations which may produce felt vibrations from those which produce vibrations which may be damaging. Note that this list may not include absolutely every kind of operation involved in road demolition and construction, or construction generally. **Some items of lesser concern could produce damage if inappropriately performed or if your house is particularly close to the work**. Indeed, some such operations are known to have produced many vibrations in excess of the FTA standard (see below). This list is provided **for those who may want to plan for documenting certain activities** around their home during construction operations.

- **Pavement breaking** - This operation, if done correctly with the correct equipment, is usually not a cause for worry. Most commonly, pavement can be "rolled up" by getting under it with a loader or excavator bucket and raising it (e.g. photo at right). This operation generally produces relatively little and short-lived vibration. Other types of pulverization/cutting equipment (e.g. Wirtgen pulverizer) can also be properly used without much concern for excessive vibration. Even a specially-designed excavator attachment can be used to roll up or break pavement without significant risk. However, there are **other, generally non-approved, methods which can cause very large vibrations and damage**. I have personally observed and repeatedly documented on video the use of a large excavator standard bucket to pound on asphalt pavement to break it on multiple occasions.[4] The effect of this was similar to being in a large number of moderate size earthquakes and caused widespread damage, to my home and many others on the street. The types of damage resulting from this pounding (e.g.

multiple breaks in monolithic concrete 180 feet from the work site) was such that it implied vibration intensities **far in excess of any standard worldwide**. Such a use of the excavator violates the Operator's Manual for the excavator in several places. I have also documented pavement being broken by **picking large chunks of it up and dropping them on the ground** to break them. This also created felt vibration, exceeded construction vibration standards and created documented damage.

- **General demolition** - Demolition has the potential to cause damage, because many of the vibrations it produces are of the ground impact variety. Impacts produce vibrations with a broad spectrum of frequencies that include the resonance frequencies of homes. The damage potential of demolition depends on the procedures and equipment used, the type of structure demolished, and the skill with which it is done.
- Pavement milling - This is a process by which pavement is ground off (see at right for a photo of a pavement miller in use) with rotating blades, rather than broken apart by impact. It usually produces a small amount of non-damaging vibration. That said, because pavement millers are tracked vehicles removing pavement by impact and moving at a slow rate in front of any given location, their use should probably not be completely disregarded as a vibration source in at least some circumstances.
- **Pile driving** - There are several different methods for pile driving. Impact pile drivers are known to cause large and potentially damaging vibrations. Vibrational or sonic pile drivers, despite the names, generally produce less ground vibration than impact pile drivers[2], although even they can be a problem if your home is sufficiently close.
- Excavation - Excavation can be done with backhoes or excavators. In our experience, excavation usually causes little vibration.

- Dirt moving - This can be done with a wide variety of heavy equipment. It usually produces little or no vibration or damage, if properly done.
- Pavement forming - This is the process of laying down the pavement. It involves a pavement former and trucks which provide a continuous supply of asphalt to the pavement former. In our experience, pavement forming or lay-down produces only minor vibrations, which do not generate damage.
- **Compaction** - There are two basic kinds of compactors, static and vibratory. Static compactors (i.e. those which merely roll the asphalt or ground) have less damage potential than vibratory compactors. Vibratory compactors (at right) are designed to produce substantial vibrations, which can cause damage in our experience (vibration record of a small portion of one day's compaction operations at left). Vibratory compactors are of sufficient concern that the Federal Transit Administration has advised against their use in "sensitive" locations, including residential areas.[1] As the



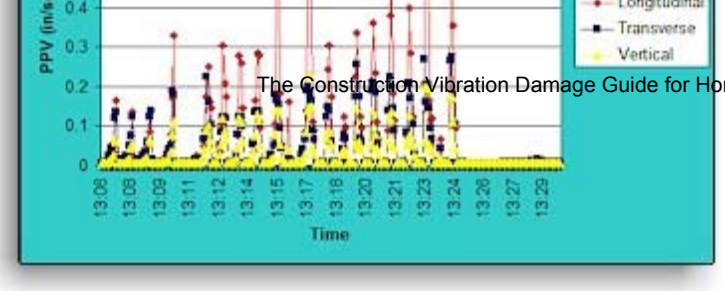


diagram at left shows, the contractor violated some or all FTA standards (starting at 0.12 in/sec for structures sensitive to vibration and going up to 0.5 in/sec for reinforced, engineered structures) numerous times during vibratory compaction at this and other locations. If you can feel vibrations occurring as a compactor approaches, chances are that the vibratory compactor is responsible. You will need to observe and document carefully the use of the compactor and any damage that may occur during its use.

- Jack-hammering - This procedure is often used in road projects, as well as many others. Perhaps surprisingly, the vibrations created are so localized that they can't normally be felt if you are more than 50 feet away.
- **Blasting** - It is well-known that blasting vibration can damage structures to varying degrees. Indeed, much of the scientific literature about vibration damage deals with damage caused by blasting. Although blasting is usually done in mines and quarries and, to a lesser extent, in new road construction, it must be done properly and at sufficient distance from structures to avoid damage.
- Other operations - Grading, sweeping, concreting, curb installation, manual operations and a host of other activities can take place during road building or other construction activities. Although there could be exceptions in specific cases, all of these are usually of little worry, if carried out properly and in accordance with accepted procedures for use of the equipment. Similarly, construction operations done by people using only hand tools pose little risk of damage in most circumstances.

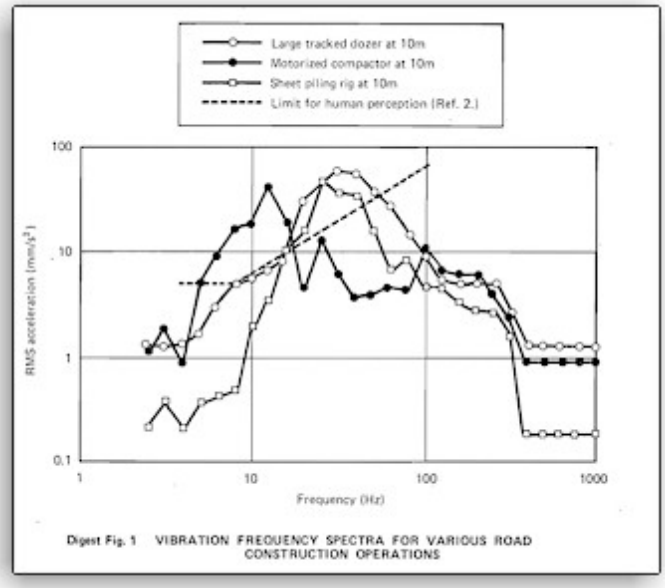
Heavy Tracked Equipment Movement

While not a construction operation, *per se*, movement of heavy equipment is a part of any construction project. Indeed, tracked excavators and dozers must move small distances (usually well under 100 feet) to perform their work at a given location. These short distance moves in the normal and approved performance of heavy equipment use represent small risk to structures.

Tracked heavy equipment is supposed to be transported any significant distance on trailers. However, we've observed and documented on video several instances (e.g. the video frame capture at right) where tracked heavy equipment was being driven on a city street for a mile or more. That movement caused so much vibration in homes that it could be felt more than a half block away and continued for more than a minute in each such case. I documented damage specifically caused by those movements.

The absolute magnitude (size) of ground vibration associated with movement of tracked equipment is often relatively small and even within some construction vibration standard limits. For this reason, it is generally discounted as a damage source. However, as

described in detail in the CVDG Pro pages, Vibration Signatures, and in abbreviated form on the CVDG page, Is Damage Possible?, **because the vibration frequency distribution is skewed toward frequencies close to the resonant frequency of the home and because the vibration created in the house can last for a minute or more, such passages can be particularly ill-advised**.



Digest Fig. 1 VIBRATION FREQUENCY SPECTRA FOR VARIOUS ROAD CONSTRUCTION OPERATIONS

Although tracked equipment movement is rarely a subject of vibration damage studies, a study from the U.K. shows that driving large tracked vehicles of the sort used in road construction (large dozers, excavators) can produce vertical axis ground vibration accelerations in excess of those caused by vibratory compactors. Higher accelerations mean higher final ground vibration velocities (PPV's) over any given time period. Vibratory compactors, themselves, are known to violate some U.S. and international construction vibration standards. Vibrations produced by driving tracked equipment have peak frequencies in the sub-40 Hz range of most concern for damage effects. The diagram at right, reproduced from the U.K. study[3], demonstrates that such vibrations from driving tracked equipment are of special concern, especially when repeated or lasting a significant period of time (more than a few seconds), even though they were not suspected of causing "architectural" damage at the time of the study cited (1977).

Vibration levels are known to vary with the weight of the tracked equipment, the speed at which it is driven, the underlayment (soil and type or pavement) and the type of track (standard or low-vibration track patterns, metal or rubber tracks) on the equipment. The U.K. study also shows that **rubber-tired vehicles usually produce little vibration above background levels**. This observation is consistent with my own observations and videotaping of movement of a wide variety of tired construction equipment in a road reconstruction project. Thus, **it is tracked equipment whose movement over distances should be monitored for vibration, not only with respect to the largest vibration produced, but with careful consideration of both its duration and frequency distribution**.

Documenting Equipment Use

If you have a problem with vibration damage, it is wise to **document on photos or video every kind of equipment used** in the work, with sufficient detail that one can read the contractor logo, equipment manufacturer and model number of the equipment used, all of which are usually readily visible on the equipment. The model number allows you to find online the specifications and, perhaps, the operating manual for the equipment. These will be helpful in understanding both vibration records (e.g. correlating the primary frequencies of compactor vibration with the vibration records) and the way the equipment was used in your area. They are usually available on the Internet free or for a small fee in PDF format from the manufacturer of the equipment. These can be an

important resource in proving **misuse of equipment**.

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1. **Federal Transit Administration** *Noise and Vibration Manual,* p. 12-14
2. **Federal Transit Administration** *Noise and Vibration Manual,* p. 12-12
3. GROUND VIBRATIONS CAUSED BY ROAD CONSTRUCTION OPERATIONS, D J Martin, Department of the Environment, Department of Transport TRRL Supplementary Report 328: Crowthorne, 1977
4. Even properly done pavement breaking can be dangerous to homes: "*With the exception of a few instances involving pavement breaking, pile driving, all Caltrans construction vibration measurements have been below the 5 mm/s (0.2 in/sec) architectural damage risk amplitude for continuous vibrations. The highest measured vibration amplitude was 73.1 mm/s (2.88 in/sec) at 3 m (10 ft) from a pavement breaker." (Transportation- and construction-induced vibration guidance manual.* June 2004. California Department of Transportation, p. 15)

Recognizing Damage

Although vibration damage to structures is usually split into cosmetic and structural types, understanding the specific types of damage which can occur, their causes, their implications and how to address them is essential to pursuing a construction vibration damage claim. On this page we'll give some tips, with illustrations, of **how to understand the various types of damage**. Many of these types of damage involve drywall or plaster cracking or other forms of distress for which you will have to look to note. In our experience, it is the rule, rather than the exception, that homeowners with construction vibration damage will feel they have no damage from the nearby construction, until they look for it with an eye to the specific and diagnostic types of damage that are discussed below.

Possible Structural Damage Indicators

Structural vibration damage is best evaluated by a civil or structural engineer with experience in viewing and evaluating such damage. If you make a claim, whether or not you have to litigate it, it's a good bet that the construction company or their insurer will want to send an engineer to evaluate the house for structural damage. Since that engineer works for the opposing side, you may or may not get straight answers, but you can express your concerns about specific types of damage and sites to the engineer for his opinion and evaluation. Eventually, you may have to bring in your own engineer for a second opinion.

In multiple discussions with engineers about vibration damage, I have learned that there are some simple signs to look for that **might** indicate that you should have an engineer check for underlying structural damage: (**Click each thumbnail to view the full-sized image**)

- **Cracks in the house slab or connected patios and driveways** - These may not indicate structural damage; but, if they are not pre-existing, they are signs that should be discussed with an engineer in the context of structural damage to the house. **Cracks in tile or grout** can reflect cracks in the underlying slab. **To the extent that the house slab and/or patios are monolithic pours (connected and poured at one time), information in the blasting vibration study USBM RI 8507 indicates that such cracks, if caused by construction, result from vibrations far in excess of any U.S. standards[3]**. Our CVDG Pro page, Inferring Vibration Levels, has more information on inferring vibration levels from damage patterns.

- **Misaligned doors and windows** - Misalignment can be seen by looking at the door in the frame. If the door doesn't show a reasonably constant spacing all the way around between it and the frame, it has become misaligned. Some doors may become difficult or impossible to open or lock, if the misalignment is large enough. Windows may become difficult

to operate when misaligned. If you also see **diagonal drywall cracks at corners of window and door wall penetrations** (see below), these are signs that the house has undergone **shear**, possibly due to vibration, which is causing the misalignment. Checking the door and windows frames for plumb, using a level, can strengthen an argument that the house structure has shifted in response to construction vibration.

- **Plumbing problems** - If you suddenly start to experience plumbing failures underground (e.g. irrigation or waste line pipe shattered) or at the point where the house supply connects at the slab to the incoming line from the street, especially in the context of other vibration damage, it may be an indicator of possible structural damage. Problems with any other lines which go underground (heating, gas, etc.) may also indicate the possibility for structural damage. If you have this sort of damage, there is a very good chance that others nearby will have it, too.
- **Cracks in dry wall with vertical displacements** - Most cracks in drywall are considered as cosmetic in nature. However, if you have cracks in which one side of the crack is substantially higher than the other side, this could be a sign of underlying structural damage. Also, any crack in drywall in which the failure is not along a join between sheets, but in the sheet itself, especially if it is jagged in appearance, may indicate a possible underlying structural issue requiring further investigation. (photo below)
- **Roof damage** - Shingled roofs will usually show little sign of damage from vibration to the underlying trusses, simply because the shingles can hide it. However, tiled roofs have penetrations which are usually sealed with concrete "cones". If these are broken, it could be a sign of structural problems. Usually breaks in the cones result in water leaks, which are also signs of potential structural problems in buildings with shingled roofs.

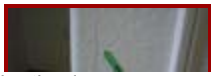
Cosmetic Damage

Many houses beyond ten or fifteen years in age will have a few (less than ten) hairline cracks along drywall seams and/or at drywall corner beads, due to slight settling, changes in temperature and humidity, or simple aging of the drywall. Most times, the residents of the house will not even be aware that these are present, because they are usually hairline cracks which are not easy to see, unless one sets out to find them. Once people find such cracks, they become more sensitized to them and look for others. The possible **existence of unseen, pre-existing cracks is well-recognized**, both in the scientific literature of ground vibration damage and by contractors. For this reason, you will almost certainly hear that your damages were all pre-existing and that you had simply not seen them in the past.

Because limited minor cracking can occur for reasons other than construction vibration, the timing of the damage is important in tying it to the construction. On the occasion of our damage, the witnessed **construction vibration in our house produced over 300 cracks, plus damage to concrete block walls and a monolithic poured concrete patio, in one day**! Additional cracking appeared later, as the job continued over strenuous objections from me and others.

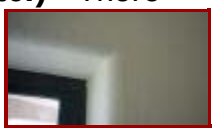
When looking at your home for "cosmetic" cracks, here are some locations you should check and ways to begin to differentiate vibration cracks from settling (or aging) cracks:

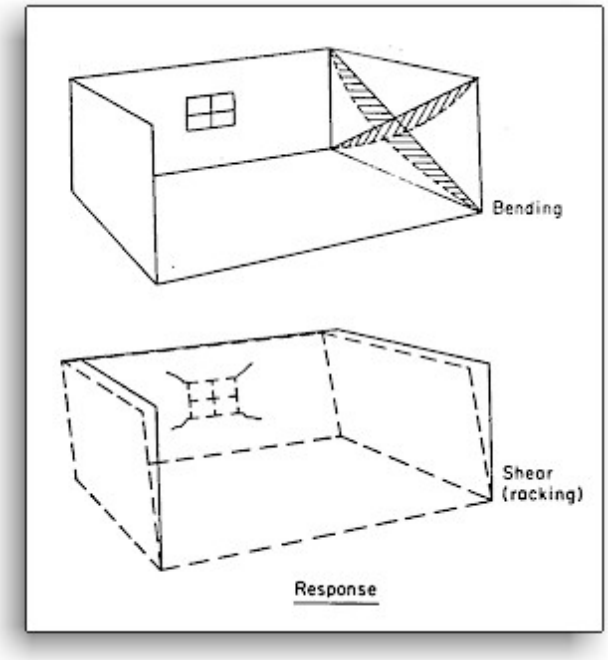
- **Linear hairline drywall cracks at corner beads and at sheet joins** -



These are common in both settling and vibration damage. Mostly, they can be differentiated only by the timing of appearance and the number of cracks which appear in connection with construction. In my experience, vibration-related cracks tend to be longer and more numerous than those caused by settling. They also tend to expand with time. Because settling and vibration cracks of this sort look so similar, documentation of the time and circumstances of their appearance is important.

- **Diagonal cracks at corners of wall penetrations (windows, doors, etc.)** - There are some characteristics of vibration cracks which settling cracks rarely share. Cracks at drywall corner beads and sheet joins can occur both from normal settling and from construction vibration. However, cosmetic drywall cracks from vibration often appear at the corners of windows and doors, running approximately diagonally from the corners. Corresponding cracks often manifest themselves outside in rigid finishes like stucco.





These diagonal cracks are due to the house being placed in shear (i.e. sections of the house moving differentially with respect to one another) by vibrations. These shearing vibrations are known in the field as **"racking" motions** (see diagram at left, reproduced from USBM RI 8507[1]). They are different in nature and consequences from the so-called "mid-wall" vibrations ("bending") which lead to pictures rattling on vibrating walls, although racking and bending motions often occur together. Such racking cracks rarely appear house wide in normal uniform settling and are often indicative of vibration damage, especially when seen in multiple structures in a given neighborhood.

- **Drywall nail or screw "pops"** - These appear as places where the "mudding" over the screw or nail is either raised, has multiple small radiating cracks or is missing entirely. If widespread and significant in number, they also imply shear forces, likely due to vibration.
- **Cracks in drywall with vertical edge-to-edge displacements** - As discussed above, these cracks often appear in situations in which the house has be subjected to shear, due to vibrations. The vertical displacements (i.e. with one side of the crack substantially higher than the opposing side) are indicative of the shear process and may signify some shifting in the frame of the house.

- **Damage to exterior finishes** - Just as vibration damages drywall, it will also usually cause cracks in exterior rigid finishes like stucco. Cracks in stucco running diagonally from wall penetrations are indicative of vibration-induced shear, just as they are in interior drywall.

- **Cracks in exterior property walls** - In the Southwest,

exterior concrete block "tumbleweed walls" are common dividers at property lines. These are also often damaged by vibration. This damage can take the form of both cracks in mortar or cracks in the blocks themselves.

- **Cracking of concrete** - Similarly, there can be cracking in concrete driveways or patios. As discussed in the USBM study, RI 8507, such cracks in the mortar or blocks can be good indicators of the intensity of the vibrations (see USBM RI 8507 diagram[2] at left), since **it requires vibration intensities well above any standard in the U.S. to break mortar, concrete blocks or monolithic concrete**.[3,5,6]

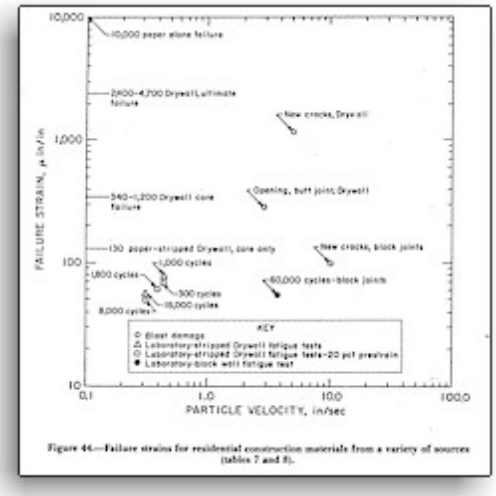


Figure 46.—Failure strains for residential construction materials from a variety of sources (tables 7 and 8).

The OSM also provides guidance on these matters in its *Blasting Guidance Manual*,[5,6]

"*Concrete, particularly reinforced concrete, is very resistant to blast vibration damage. Cracks will not normally appear in concrete below perhaps 10.0 inches per second, a velocity that is not only far higher than OSMRE regulations permit, but that would normally cause undisputed and quite extensive cracks to occur to plaster, gypsumboard and brickwork. Damage to concrete is therefore normally accompanied not only by exceptionally high velocities, but also by other, and obvious damage.*" (emphasis added)

The CVDG Pro page, Inferring Vibration Levels, has more information on inferring vibration levels from damage patterns.

The OSMRE Blasting Guidance Manual provides substantial advice, very similar to that offered here, for identifying damage and associating it with vibration events.[4]

Other Property Damage Causes

Construction may cause damage for reasons other than vibration, *per se*. Breakage of gas or water mains can lead to damage to property that will require fixing. If any excavation must be done on your property to further the construction (e.g. connecting meters to water mains), that is sometimes poorly cleaned up, if at all. If you have damage of these types, they should be included in your damage repair claim.

Continuing Damage

The types of damage seen here may continue to appear for many months after the construction ends. **Most engineers will advise waiting at least six months before fixing any construction damage**. The reason for this is that the adjustment of the home to stresses placed on it by the vibrations isn't necessarily fully completed when construction or vibration ends. Thus, you may continue to have newly appearing damage after construction is finished. This doesn't necessarily mean the house is experiencing damage from some new source. It's just the slow resolution of the underlying stresses brought

about by the construction vibration. In my case, it was over a year after construction end that damage **mostly** stabilized.

Noise Issues

Construction almost invariably results in noise issues ranging from minor discomfort, to, in extreme cases, potential health issues. While noise issues are outside the scope of the CVDG, homeowners should be aware of their possible contributions to nuisance and inconvenience during the construction. The FTA Noise and Vibration Manual has extensive information on noise impacts that homeowners may need to read.

Talking with Neighbors

If you see significant damage appear suddenly, during a construction job adjacent to or nearby your home, you should talk with your immediate neighbors about any damage they might have. If only one house is damaged, the construction contractor can blame the damage on the house or you; if several are damaged that argument gets increasingly difficult to sustain. Chances are, your neighbors will not have looked for damage nor will they know of any, so you will probably have to tell them what to look for in their own houses. The CVDG will help you and them know for what they should search. Your neighbors may also have a better idea of what was actually done during the construction, if they are at home through working hours. Learning from neighbors and documenting damage in their homes is a critical issue which is discussed in more detail on our page, Recording Damage.

This is, by no means, an exhaustive listing of all the kinds of vibration damage which can occur. Instead, I suggest it as a starting point for those who may feel that they have construction vibration damage and want to know for what they might look to find.

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1. USBM RI 8507, p. 18
2. USBM RI 8507, p. 44
3. USBM RI 8507, p. 45
4. OSMRE Blasting Guidance Manual, pp. 121-122
5. OSMRE Blasting Guidance Manual, p. 121
6. "*When major, structural damage, such as the collapse of brickwork, extensive and serious cracking threatening structural integrity, or concrete cracking is found (apart from the small drying-out or temperature cracks to be found in virtually all concrete) then either the ground motion exceeded 3 or 4 inches per second, or some other reason exists for the damage.*" OSMRE Blasting Guidance Manual, p. 112

Recording Damage

Possessing a clear and unambiguous record of construction vibration damage and activities is critical to pursuing any damage claim. This page discusses some of the kinds of documentation that can be helpful. Note that **you will need as much documentation as you can get**, whether or not you have to litigate to get your damage covered. Indeed, you can reduce the chances of litigation if you have enough documentation of the right types. The recommendations which follow assume that you might have to litigate, simply because it may be much to your disadvantage to begin documenting only when you realize that litigation might be necessary.

Purpose of Documentation

Documentation has several purposes. First, it provides a clear record of the nature of the damage, the timing of its appearance and its progression with time. Second, it allows you to correlate the appearance of the damage with ongoing construction activities to help establish the causal link. Third, it provides a memory backup for a claim that may well take years to get resolved, especially if the damage is extensive. Fourth, it is necessary if your damage is so severe that you are forced to litigate the claim, although litigation should never be your first choice to resolve any dispute. **Without good documentation, your claim is virtually certain to be ignored**.

Recording Your Damage

You should begin recording the damage to your property the moment you begin to suspect that construction may be responsible for it. For many people, **photography or videography are readily accessible means of documenting the type and locations of damage**. I prefer high quality videography over photography, since you can document the location, time and extent of damage by narration on the video. Individual frames from the video can be easily extracted when still photos are needed. This video narration saves the need to keep a separate log of the same information for still photos.

To the extent possible, **your narration should be confined strictly to the necessary facts of the situation** (date, time, nature of activity, damage site, etc). You will not enjoy having any angry or sarcastic comments you make played at trial, if you have to litigate your case. If your camera automatically records date and time on the video (or you can enable it to do so), you need not duplicate this information by narration. You should **not** talk over construction-related noise, beyond any absolutely necessary narration of time, date and location. Ambient construction noise may turn out to be more important in a litigation context than your conversation.

When you record damage, **pay attention to getting clear images of both the damage**

and its context. Close-up images are good for seeing details, but in a few months you will have probably forgotten where, exactly, you recorded them. Images which allow you to place the location well are often not sufficiently detailed to understand the nature of the damage. Make sure you record at the highest resolution of which your camera or video camera is capable. In my view, it is best to use a camera which records at its full, uncompressed resolution. For photos, this means using the RAW format, rather than JPEG, and setting the camera to its highest resolution. For video, this means using a video camera that records at its highest resolution to digital or analog video tape, rather than one which records compressed MPEG files to an SD memory card. By its nature, compression of photos and video to JPG and MPG file formats loses some information permanently.

Continue recording newly appearing or changed damage for at least 6 months after the end of the construction. Once the house has been stressed by vibration, cracks will likely to continue to form for some time after the end of the project. Document the new cracks as they occur, noting the date of appearance. You can note any changes to older cracks that may accumulate with time, by placing dated pencil marks on the wall indicating the end of the crack at that date. You can also place the same information in a notebook, with a careful description of the crack location, so that it can be distinguished from others. Since cracking will continue for some time (at least six months), it is probably best not to attempt repair until the cracking and any other damage becomes stable.

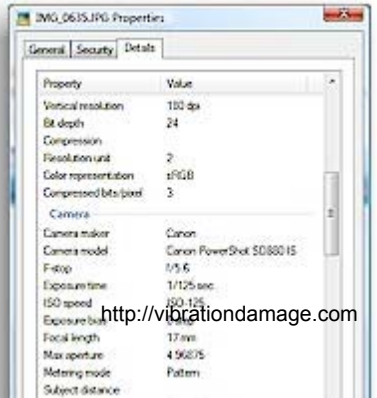
Most people who have video cameras have some sort of video editing software (e.g. Pinnacle Studio, Sony Vegas) included with the camera. Windows includes a limited capability video editing program, called Windows Movie Maker, as well. One of the most valuable things you can do with your video is to use it as a source of still photos by getting "frame grabs". Most video editing software will allow you to get these. You will also need editing software to create DVD's of your video for litigation production, if you have to sue. Some really capable editing software also allows you to zoom in on video for better viewing and filter the sound track to allow construction sound to be better heard over any extraneous noise.

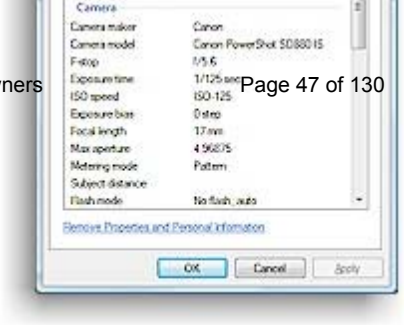
Mapping the Damage

Because of differences in effective distances of different kinds of vibration interactions with the home, the value of mapping the damage becomes obvious. The simplest way of doing this is to take a floor plan of the home and walk through, noting each site of damage on the floor plan. Such a map is helpful in so many senses that most people should take the time to do one.

Viewing and Using EXIF Data

Both digital cameras and digital video cameras record automatically specific information in the saved files ("EXIF" - Exchangeable Image file Format - data) which include the camera used, the time the images were recorded (taken from the camera clock) and much other useful information. This information can be viewed in Windows Explorer (see example at right) or just about any video editor or image





processing program. To view your photo EXIF information in Explorer, right-click on the file name, choose Properties, then the Details tab. This EXIF information is a good way to find out the true dates of recording of digital images, since the computer file dates may not reflect accurately the date/time of recording. Note that one can remove the EXIF information from digital images in Windows; if digital photos or video are produced without such information, **you should question their authenticity**.

Damage to Neighbors' Property

The first question most people will ask about construction damage claims is whether there is damage to other nearby properties. It is a good bet that most construction companies will deny any such damage, whether or not such a denial is factual. In one case with which I'm familiar, construction company witnesses repeatedly denied under oath any other damage claims, until faced with written complaints from neighbors and records of past legal actions against them. In this example, the number of additional complaints increased from 0 to at least 6 in about ten minutes.

While **you should not make a point of trying to stir up litigation**, as this is never the best solution, you should make every attempt to inquire if your neighbors have noticed any damage to their property. Chances are that they will neither have looked for nor noted damage. So, you should be prepared to tell them where and what kind of damage for which they should look, based on the type of damage you see in your own home. The CVDG page, Recognizing Damage, has tips about what you should look for in a vibration damage situation. In my experience, even those with substantial damage will not be aware of it. If they are, they will not be able to make a causal link to construction, because they were not present during the construction hours. One neighbor was convinced that he had no damage from the construction vibration, then came back a half hour later to report that he had more than 50 cracks traceable to construction vibration; by the end of the construction, he had three times that number.

If your neighbors have damage for which they would like to seek reimbursement, they should **make a formal written complaint** to both the contractor and the sponsor or funder of the construction work. Written complaints cannot be ignored. They can be a great help in protecting the rights of the homeowner, because the existence of such complaints can be a subject of questioning of the contractor.

If the neighbors make such written complaints, try to get copies of them for your records. If you can get them to do so, it's not a bad idea to have neighbors write a document in their own words describing any vibration damage they have and how it might have occurred. Make sure they sign and date it, and, if you want to be really careful about it, have it witnessed and notarized. It may not be possible to use such a document at trial, unless the neighbor is willing to testify at the trial. But, it can be very useful in keeping dishonest contractors from making "he is the only person that complained" statements. Keep in mind that, because of possible disclosure-related decreases in their property values, **some neighbors will be unwilling to admit even obvious damage to their property**. For the same reason and, perhaps, others, neighbors may also be reluctant to support your attempts to resolve a damage claim.

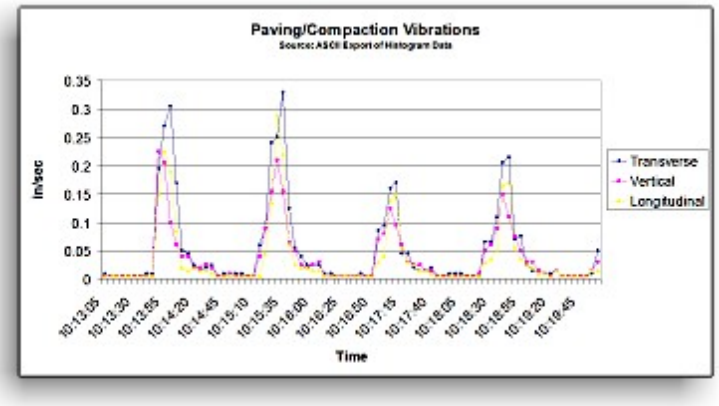
If nearby houses go on the market during the construction or in the few months immediately thereafter, that can be a perfect opportunity to examine those homes, especially before they have been prepared for sale. Since houses are often painted prior to sale, the effect of painting is to temporarily disguise some cracking in drywall. Ask for permission to photograph damage in neighbors' homes. Most will agree to that. Give them copies of the photos if they ask for them.

Your evidence of damage to other properties may or may not be directly admissible as evidence in a court case, but will strengthen your position in trying to settle your claim outside the court system. Also, having photos of damage to other homes in the construction area may force the defendant to seek a **motion** *in limine* to exclude all that evidence from the trial. Even if that evidence is excluded, the filing of such a motion will indicate to the judge that your claim is likely legitimate, given the widespread damage. Having the trial judge recognize the credibility of your claim can be helpful in many subtle ways during trial, even though the judge isn't actually biased in your favor.

Documenting Construction

Just documenting the damage will usually not be enough to establish your claim. You need to **keep a record of as much of the construction activity as you can**, particularly any actions which you believe may be responsible for causing or worsening damage. It is amazing how much construction company employees can forget about their own actions, when it is in their interest to do so (and it often is). Again, videotaping is an excellent way to do this.

Most people cannot be watching the construction all the time, unless they have security cameras that can record full-time. Of course, such constant recording means you have a huge volume of video to sort through and, if it comes to litigation, produce to the opposing side. If you can't record full-time, then you should try to record a representative cross-section of all construction operations, with particular emphasis on occasions and operations which you believe may have caused or worsened damage. If you feel vibrations in your building, that's usually a sign that you should record for the duration that such vibrations persist.



Make sure that you get both close-up and perspective shots as you did in recording damage. **Recording the people carrying out the operations is just as important as recording the operations themselves**. In one case with which we are familiar, **several** construction people testified under oath that people in their company would "never" do things which they were captured on video actually doing or watching being done. **If you have to take a day or two of vacation from work to record critical operations (pavement removal, pavement and/or soil compaction, pile driving), it may turn out to be the most important time you will ever take off from work.**

In documenting damage, you should make every attempt to **avoid direct interaction**

with or visibility to the construction crew. If you interfere with their activities or even if you simply make your videotaping or photography obvious to them, you could face a number of undesirable results. You are also likely to find that you will cause the crews to modify their activities for as long as they can see you.

If they know you have filed a claim, they may become outright hostile. In our situation, people on the construction crews that we had never met gave us **obscene gestures on multiple occasions, while we were inside our home**, several of which occasions we captured on video. On another occasion, when vibratory compactor use was causing very large vibrations, a notification of the construction crew produced not only no reaction, but no acknowledgement of my presence, as recorded on video. These recorded incidents made for an interesting comparison opportunity at trial when the contractor witnesses were talking about how much concern they had for the people living along the street.

Meetings, Phone Calls, Conversations

From personal experience, I believe it is a good idea to videotape every meeting you attend with people from the opposing side which deals with the damage or construction. This includes visits by "experts" to view your damage, especially those hired by the construction company or their insurer. Chances are good that you will wish you had videotaped such meetings and visits, if you don't do so. Keep a record of exact times of these visits. Also keep notes on relevant incoming calls which include the caller, time and subject of conversation; **exact call times are easily gotten from Caller ID**, if you have it. These call records should go into your **timeline narrative** (see below).

Other Documentation

You should have more than just videotape and photos. These are extremely valuable, but you may see things that are not recorded. Also, if you have lots of images or video, it may be hard to locate specific information if you have to go through all the video each time you need some piece of information. It's an extremely good idea to **go through all your video and images and "index" them in a database or spreadsheet**. This will save you an immense amount of time going through video to look for various events. With such a searchable index, it's "one and done". You should include in the index at least fields for date, time, location of item (DVD timing, file name, etc), a short description, a standardized set of keywords and a special field for comments. If you have lots of video, it will take you a lot of time to do this, but will save you immense amounts of time later when you need to find specific clips.

In most projects, some kind of **pre-construction survey** will be done by the contractor. Sometimes, this is comprised of nothing more than a contractor employee walking or driving by your house recording video of the outside condition of the house and property. A far more valuable pre-construction survey will involve the contractor seeking permission to come into your home and videotape of photograph its interior and exterior condition. You should **only allow such an interior inspection under certain conditions which you control**. The conditions should include explicitly that **you are provided a copy of the inspection video or photos** within a specific period of time after the inspection. You can find some example documents that you could use to document these conditions and agreements on our Conditions Documents (CVDG Pro) page. I strongly advise that you use these or similar documents. Such signed documents may be your only

leverage in getting copies of the inspections, short of an extended battle in a lawsuit. Even if you have no damage from the ensuing construction, the pre-construction survey can be valuable to you for insurance documentation.

The contractor may record other video or photos during the construction. If you have to sue, you should include **provision of copies of the contractor video and photos** in any production requests you make during the discovery period of the lawsuit. In my own case, contractor video helped invalidate the claims made by its vibration monitoring technician.

Use a Timeline Narrative

You should also start what I'll call a "**timeline narrative**" (see graphic at top of page for an example of the layout). In this narrative, you will record everything of interest, including appearance of damage, construction activities, conversations, meetings, damage assessment visits to house, dates and times of phone calls (from Caller ID if you have it), etc. that occurred on a given day. **This narrative should be as factual as possible**, lacking any extraneous comments about the motivations, parentage or unsavory habits of those whose actions are recorded there. Don't worry too much about perfect grammar or spelling; the important thing is to have an independent record to supplement your video/photo records. Don't worry about recording every detail in the narrative; just indicate those matters that you see as important on that day. Although they should not be the focus of the timeline narrative, all word processors allow you to include photos and other graphics in the appropriate locations, if they are necessary to support what you write. It need only be two or three paragraphs a day, but you should start it as soon as you realize damage has occurred and continue it every work day (and any weekend day on which notable events occur) for at least as long as the construction lasts in your area. Such a timeline will be invaluable to you in keeping track of facts and events, especially if you have to litigate your claim.

Remember that any documentation you generate could be produced in litigation, so keep your comments and writings factual and to the point. Avoid outright speculation of any sort. If you don't know it as fact, don't include it in anything you write. If your neighbors tell you anything relevant to the damage, document it, too. Give your attorney a copy of the narrative for his own use; this will help protect it from production under the "attorney-client privilege" exclusion.

If you live in an earthquake-prone area, you will want to get complete records of earthquakes for your area in the month or so prior to the damage appearance. These are easily obtained from the Internet. Such records will help address counterarguments (CVDG Pro) that your damage was caused by a minor earthquake, rather than vibration from construction. You may also want to get Internet weather records for your location for the period a month or so prior to the damage, to combat claims that high winds or temperature changes caused the damage. These largely spurious claims will be likely to disappear if you have the records, but could be problematic in pursuing your claim if you don't have them.

Safeguarding Your Documentation

Once you've gone to the trouble to generate and organize all this documentation, you certainly don't want to lose it to a computer hard disk crash, a fire or some other disaster. Chances are, you'll be sending some of the material, if not all, to your attorney, but you shouldn't depend on law firm employees being able to find quickly everything you have sent them. For most people, the simplest way of backing up critical digital data files is to write them out to a rewritable or read-only DVD. These days, most people have DVD burners in their computers. Once a week or so, you should rewrite the DVD to include all new data information.

One DVD will probably hold all your written data and images, but will certainly not hold all your video, if you have any significant amount. Video files are huge in their uncompressed state. For backing these up, an extra hard disk, either internal or external is the best medium. A 1 Tb external USB hard disk for this purpose can be bought for around $50 these days. Once you have such an extra disk set up, you can use any backup software you might have (including that included with Windows) to regularly back up your video and other documentation. If you have an account with an online backup service, that's a good option, too. If you're generating a lot of data, daily backups are needed; if you're generating more moderate amounts, weekly backups should be fine.

If you file suit, you will have to **produce much or all of your documentation** in response to discovery requests. Video is best produced on DVD's, which use a "lossy" compressed MPEG format. What this means is that the DVD's, while adequate for viewing and production, will not have all the information (e.g. EXIF data) in the original uncompressed video files (e.g. .AVI format). So, **a production of video on DVD's does not allow you to discard the original video files**.

Data, for example, photos, digital documents, scientific papers, etc., can also be put on CD-ROM's or DVD's. **You should keep exact duplicates of everything you produce, both in hard copy and as digital data**. These duplicates should be stored away from your home. You can send these data disks to family members for off-site storage or get a safe deposit box. If you need to store a few critical digital documents off-site, sending them to a GMail, Hotmail, or similar online e-mail service is a good option. Just **e-mail the documents to yourself as attachments** and the mail services will maintain the backups for you at no cost, at least to the limits of your allowed account storage.

I cannot overemphasize the importance of keeping up-to-date backup copies of all your information. If you get a production request for information which you have had, but have lost or cannot find, **you could be sanctioned by the Court** for destruction of the information (in legal terms, "**spoliation of evidence**"). Of course, you cannot use anything you have lost as evidence. Worse yet, any part of that evidence you may still have could be **excluded from the case**, because it is incomplete and, therefore, "prejudicial" to the opposing side.

Is That All?

I wish I could say that the answer is "no"; unfortunately, that's probably not the case. Each situation is individual, because the damages are unique to each structure, the people different and the legal jurisdictions as variable as the people. In general, the more damage you have, the more difficult it will be to reach a resolution and the more

documentation you will need to support your claim. Of course, the larger your claim, the more motivation you will have to do that documentation. The documentation items mentioned here should give you a good start on what you will need. Even though preparing all this documentation is a lot of work, it will be well worth your time, if your damages amount to tens of thousands of dollars (or more), as is typical.

Damage Repair

Understanding the amount, types and costs for repair of construction vibration damage is both time-consuming and ongoing, since damage may not stabilize for months or years after construction stops. Nonetheless, you must thoroughly document all the damage you may have before you can begin to estimate repair costs and needs meaningfully. On this page, we'll explore some of what you need to know about the general process of estimating costs and carrying out damage repair in a vibration damage claim.

Getting Repair Estimates

You must usually get more than one estimate for a given item of repair cost; three is typical. These should be gotten from **licensed** contractors. If you have extensive and varied damage, you will need a licensed general contractor, because of the greater scope of the work. Depending on when you start the process of obtaining repair estimates, you may need to have them done more than once, since the appearance of damage is usually not complete for six months or more after the first damage appears or after completion of construction.

In getting estimates, make absolutely certain that the estimates include **line items** for repair of **all** your damages, of whatever type, and that every type of damage that is to be repaired is covered in those estimates explicitly, with dollar figures attached to each item of repair. Any ambiguity in the estimate will probably end up being paid for by you.

In our experience, it took several revisions of estimates to get them complete; some potential repair contractors simply never got them right. The ones who can't or won't give complete and accurate estimates should be stricken from your list of potential repair contractors. Get the estimates in writing on company letterhead. This is necessary because you will likely have to produce them for any settlement negotiations.

If there is possible unseen damage (e.g. cracks in a concrete slab under carpet or tile, damage to HVAC systems or plumbing, roof and truss damage), investigate it to determine whether there is damage not easily visible to someone making a short examination (e.g. a repair estimator). Make certain that your estimates are for **proper and permanent repair**, not simply painting over cracks or other damage. Get explicit language in the estimate as to the general methods of repair. **Cracks which are "fixed" by painting over them usually reappear in a few months, leaving you back where you started**. Depending on the location and size of cracks of drywall, it may be necessary to replace whole sheets, especially if there is an offset in height between the two sides of the crack. The standard for repair is that you are entitled to the return of your home to

its pre-damage condition, so you have every right to demand proper repair. To find out what kinds of damage you should look for and seek repair of, if found, see Recognizing Damage.

Emergency Repairs

If the construction damage has resulted in water leaks or other types of damage requiring emergency repair to prevent further consequential damage (i.e. damage resulting from the initial damage), you may have to proceed with doing those emergency repairs well before you reach any resolution of your claim. If so, document the conditions which forced the early repair (i.e. the "before" and "after"), then do the repair yourself, if you are qualified, or have it done. In either case, it is wise to document elements of the repair on video. Save each and every invoice for the work, whether you do it or someone else does. If you do the work, you are entitled to reasonable reimbursement for your time and materials in doing emergency repairs.

Clear any emergency repairs with your attorney, if you have one, before you have the repairs done or you do them yourself. Strange as it may seem, if immediate repairs are required and you fail to do them, you may be faulted by the construction company's attorneys for "negligence" in failing to repair the damage done by them, by "contributing" to consequential damage.

Other Repairs

Non-emergency repairs should probably not be done immediately, as stress relief in the home structure, and damage appearance from it, may not be complete. Also, waiting to do the repair preserves the evidence, if you must litigate your claim. However, you may choose to do some repairs, e.g. damage to landscaping or concrete damage to driveways, just to restore the appearance of the home from the street. Just as above, document the "before" and "after conditions" by videotape or photography. If you must remove debris or do other work caused by the construction before you can do the actual repair, document and seek reimbursement for that as well as your repair and the time and materials used to perform it.

Other Costs

If your damage is extensive, you may have to move out of your home completely to allow repair. **Moving and storage costs can easily be as much as the repair itself**. Get full estimates for the moving costs as you did for the repair. Include any special costs (e.g. boarding of pets) that are necessitated by the move. Some particularly large or sensitive items (e.g. a piano) may require special moving and storage, as well as a tuning after you return to your home. You are also entitled to your living costs, over and above your normal ones, while you are out of your home, so you should get estimates for lodging comparable in quality to your home. If you have large amounts of frozen or other food for which you will have to provide suitable storage, make sure that such special storage is included in your estimates. The estimates you get must reflect your excess costs, over and above those you would incur if you could stay in your home, in full and accurately.

Disclosure Costs

Note that, if you have extensive damage of either cosmetic and/or structural types, **your**

loss may not include only the repair-related costs. In just about all jurisdictions, an owner is required to disclose any significant damage, even if repaired, to any potential buyer of the property. If you fail to make this disclosure, you may be putting yourself at legal risk for the irresponsibility of the contractor. Most real estate people will tell you that **this disclosure requirement can result in a significant loss of value of the property** (e.g. an estimated $100,000 in one case of which we are aware), even after the damage is repaired.

You will need an appraisal from an appraiser experienced with damaged homes to understand this potential disclosure loss prior to determining the value of your claim and your course of action in resolving it. A qualified real estate broker may also be able to do this, too. If a real estate expert uses "comparables" in your neighborhood to estimate loss in value, make sure that those are truly comparable. If your home is unusually large, custom-designed and built or has special features not found in most homes, real comparables may simply not exist. Then, the person doing the appraisal will have to rely on his knowledge, expertise and experience to come up with a disclosure loss estimate.

It is also wise to consult a real estate attorney to learn about your disclosure responsibilities in your jurisdiction when you sell a damaged house, even after it is repaired. Make sure that you keep copies of any engineer evaluation reports you may get which indicate the nature and extent of the damage, so that you can support your disclosure statement.

Seeking Damages

You should not attempt to overstate your damages or to charge more for their repair than is "reasonable and customary". However, you should seek full reimbursement of the full and **real** costs of repair. Think through very carefully what those costs are and then document them as well as you can. You can be certain that **every aspect of those costs will be questioned by the contractor, insurer or opposing counsel**, so make sure that you understand and can justify every dime you seek. You will have been put through more than enough, if you have significant damage, to be forced to foot part of or the entire bill, simply because you weren't aware of some damage or didn't document it.

Pursuing A Claim

How you pursue a legitimate vibration damage claim can involve the most important decisions you will make regarding it. Just about **any fair resolution outside the legal system will be cheaper and faster than filing suit**. If your damage claims are large (e.g. over $100,000), you may be forced to file suit. **Legal action should be your last resort**. Below we will discuss some of your options in dealing with a claim.

Your Homeowner's Policy - Ground Movement Exclusions

The first thing that most people think to do when they have an issue with some kind of damage to their home is to call their homeowner's policy insurer. Of course, anyone who has dealt with an insurance company on any substantial claim knows that principle rarely enters into the company's thinking. Insurance companies make the decision to pay or deny claims strictly on the monetary issues and their estimate of whether you will be able to fight them or not.

Before you report damage or meet with any insurance company, yours or theirs, it's a good idea to know exactly what your policy says. Many homeowner's policies will have **"earth movement" or similar exclusions**. These exclusions were originally intended to eliminate coverage for earthquake damage, but can be s---t---r---e---t---c---h---e---d to exclude vibration damage coverage. You will want to check your policy for this kind of exclusion before you contact the insurance company. "What you don't know can hurt you" when it comes to insurance coverage, to quote a particularly apt current home insurer ad running in the U.S.

Such uses of ground movement exclusions are seemingly self-serving on the part of the insurance company, but they ignore one fundamental fact about vibration damage. Vibration usually causes little or no permanent change in the position of the ground or its constituent particles and structures (see Vibration 101 for more). Thus, in most cases, there is no actual permanent "ground movement" of the sort caused by earthquakes that could provide supporting evidence for use of such an exclusion.

Read the language of your homeowner's policy carefully, perhaps with an attorney, to make sure of what any such exclusion really covers. If it does not mention vibration damage explicitly, you can fight the use of the exclusion. There are many attorneys in the U.S. who specialize in insurance litigation who can help you. If the policy includes such a specific and broad vibration exclusion, **find a new insurer. A broad vibration exclusion makes the policy essentially worthless.** Since all houses experience slight vibration at some base level from passing traffic, occasional sonic booms, or even your movement within the home, such an exclusion could be used to deny coverage for virtually all forms of damage, possibly excepting a fire.

A legal analysis of vibration damage exclusions in insurance policies,[1] indicates that the

applicability of general vibration exclusions in construction vibration damage cases depends on both the specificity of the exclusion and the jurisdiction. The majority view is that such general vibration exclusions apply only to natural, not man-made, vibration events, but this view is not universal. Additional legal analysis is available for some older cases.[2] Read your policy and examine the cited articles for more information. Some insurance companies in some locales will sell you a policy that covers vibration damage explicitly for an additional fee.

Insurance Experience in a Vibration Damage Case

We are aware of two examples where the insurance companies involved denied construction vibration damage claims, based on "earth movement" exclusions, in spite of the fact that there was no objective evidence of actual earth movement (i.e. cracking of soil), nor were the adjusters qualified scientifically to make such judgments. One of those companies completely rewrote its policy at the next renewal to include so many vibration and movement exclusions that the policy basically insured nothing. **That same company also denied coverage under an umbrella policy**.

A third insurance company in that vibration damage incident paid the claim for vibration damage involving water pipe rupture in a third home, but dropped the homeowner as an insured. **Your insurance company may well cancel your coverage**, even if they don't pay your damage claim. The mere fact of your having made a claim, whether or not it is paid, also means that **most other insurers will not insure your home for at least a period of years**. It doesn't make any difference whether you have ever filed a claim of any sort or amount prior to your vibration damage claim.

Worse yet, the shared claims databases used by insurers often carry incorrect or duplicate information about claims. In our experience, it is virtually impossible to get errors in the databases corrected, short of suing the insurance company. Thus, you may get a "**quadruple whammy" - the damage done to your home, the cost of repairing it yourself, being forced by your insurance company to take responsibility for someone else's irresponsible actions, and having to fight to correct errors in the claims databases** shared by most insurers. While the examples given here are derived from experience in the construction vibration damage example with which I'm most familiar, several others from different states in the U.S. have written me with similar stories of their own coverage denials. If you can get your insurance company to cover your construction-related vibration damage, it will be faster and easier to handle that way, but that's a big "if".

Dealing With Your Insurance Company

It takes scientific knowledge and considerable documentation to support adequately a valid vibration damage claim. You will probably not have such information assembled when you first talk to your insurer after the damage occurs, even if you can do it at some later time. **It is probably wisest for you to offer no suggestions to the insurance company representatives regarding what you believe may have caused the damage**, either on the phone or when they visit your home. This allows you to be completely truthful and open about the damage, without unintentionally biasing the insurance company's judgment in any direction.

You may believe that construction was responsible for the damage. But, your belief is not proof, nor are you obligated to share that, as yet, unproven belief with the insurance company. **Be helpful and thorough in showing the damage, but let the insurance company draw its own conclusions and provide its own verifiable support for those conclusions**. If you are asked what caused the damage, simply say that you don't know. Such a statement is probably fully accurate in the overwhelming majority of situations.

You should **ask the adjuster or other representative of the insurance company about his educational background** and note the answer, along with the name of the insurance company representative, in your timeline narrative. Usually, the adjuster will have little or no scientific or engineering background that would allow him to make knowledgeable judgments regarding damage causation (CVDG Pro). Knowing the background of the adjuster and anyone else involved at the insurance company can help you, if you are denied coverage without a proper scientific basis.

The adjuster will usually take an extensive set of photos of damage to your home. You should ask the adjuster for copies of the photos or even make provision of copies a condition of access to the home. The insurance company photos can be particularly valuable as documentation, since nobody could believably argue that the insurer has any reason to overstate or fabricate the amount and type of the damage.

Contractor Insurance

Most large construction jobs are insured, both by practice and by contract requirement. The contractor likely will refer you to their insurance company for your claim. Thus, the insurance company for the contractor will handle the claim. However, you will almost certainly be denied if your damage is significant. Then, the negotiation process will start. Your weapons are your damage, documentation and determination. If you are substantially lacking in any of these, you will probably have little success.

Construction insurers are not used to paying any large claims and will fight doing so in your case, if you have more than minimal damage. **Be honest with the insurer, but don't assume that they are on your side or care anything about your problem**. Remember, they work for the contractor (if for anybody, but themselves), not for you. The contractor insurer's representatives will only help you if they believe that is the cheapest course of action for the company.

Paying for it Yourself

If you cannot get the contractor or insurance (yours or theirs) to pay the repair cost, amounts less than $10,000 are probably best addressed by proceeding with fixing the damage yourself and getting on with enjoying your life. Pursuing a claim can take years, hundreds of thousands of dollars, and immense amounts of your time, if you have to litigate. There is no guarantee that you will win at trial, no matter how strong your case or skilled your attorney might be. If you choose to pay for the damage yourself, you should still **inform the contractor of the damage immediately**. Taking such an action **may** help avoid minor damage turning into major damage, whose repair you might not be able to finance. Of course, you will be doing all your neighbors a favor too, by helping to prevent (additional) damage to their homes, assuming the contractor is willing to listen to you and act accordingly.

Amicable Resolution

Once you have **notified the responsible parties of the damage** in as timely a manner as possible, your next course of action should be to attempt a resolution directly with the contractor and/or its sponsor for the work. This is one reason why you need to notify the contractor as soon as you detect damage that you feel is construction-related. You should be open about the damage and allow inspection of it by any party with a legitimate connection to the contractor or sponsor. It may be wise to set some ground rules for those inspections (see the Conditions Documents page in the CVDG Pro). It is not in your interest either to maximize or minimize the extent of the damage. Most houses and properties have a few hairline cracks or other slight damage existing before the construction start. Where those exist, admit them freely. Your goal is to arrive at a fair settlement (CVDG Pro) which allows you to repair existing damage and stop further damage, not create extraneous arguments and defenses where none need exist.

Avoid threatening lawsuit, unless you are willing to carry through on the threat in a meaningful way. This will likely cause the contractor to involve their own attorney and will cause you to lose the moral "high ground". Once that happens, the chances of resolution without legal action decrease and your costs will go up accordingly. Instead, make reasonable requests that accurately reflect the nature of your damage. Keep in mind that it will cost the contractor or its insurance company at least as much to litigate the claim as it will for you, so both parties have an interest in avoiding litigation.

If the contractor retains an attorney or has an attorney write you a letter discounting your legitimate claims or even threatening you, you are well-advised to begin conversations with an attorney of your own choosing, even though you may not retain that attorney immediately. **Do not talk with the opposing attorney and do not participate in any meetings or conversations with that attorney, unless you are also represented.** See another of the CVDG pages for more information on choosing and using an attorney to represent your interests.

Administrative Courts

Many states use administrative courts to resolve claims against state agencies, much like the same kind of courts used by the Federal government to resolve disputes on Social Security disability eligibility. If your claim involves damages done by a state agency in the performance of its work, you may want or be forced to file a claim in an administrative court, rather than in state or Federal court. **You should be represented by an attorney in any action brought before such a court**. Although you should consult an attorney for more information on this topic, keep in mind that work done by a contractor for the state is usually not subject to action in the administrative courts. In those cases, you will have to seek damages from the contractor in a civil case.

Administrative courts work much like regular courts. The judge is an employee of the agency or of the state. In an administrative court, there is no jury. The administrative judge hears the case and makes the decision. You offer your evidence in much the same way. Judges in such courts are more educated than the average juror, so your case can be presented on a somewhat higher technical level, with less educational material, than might be appropriate for the typical non-technically-trained jury. Cases in administrative courts are often allocated less time than would be allocated in a civil case, so

conciseness and focus are critical.

Litigation

Litigation is your last option if you cannot arrive at some reasonable understanding with the contractor or their insurer - especially if you have a lot of damage. **Litigation is something that should not be undertaken lightly** or in the absence of a good deal of supporting evidence. A decision to litigate should include considerations of the dollar amount of your damage, the quality and quantity of your causation evidence, your ability to finance litigation and your own willingness to commit the time and put up with the hassle of pursuing a legitimate claim. For more on the litigation process, take a look at our page, Involving an Attorney.

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1. *Are Damages Caused By Blasting or Other Man-Made Earth Movement Covered Under Your Insurance Policy?,* Larry Bache, http://www.propertyinsurancecoveragelaw.com/2013/04/articles/insurance/are-damages-caused-by-blasting-or-other-manmade-earth-movement-covered-under-your-insurance-policy/
2. *RECENT DEVELOPMENTS IN PROPERTY INSURANCE LAW*, W. A. Schreiner, *et al.*, Tort Trial & Insurance Practice Law Journal, Fall 2011 (47:1), pp. 481-482

After the Claim

Once you have notified the contractor and the sponsor of your ground vibration-related damage, things will probably begin to happen fast, for at least a time. Here's a little of what you might expect and how you might handle it. **If you retain an attorney, inquire for direction and always follow it.**

Viewing of the Damage

Almost immediately after you report it, you will likely get requests for various people to **view the vibration damage**. The more extensive the damage, the more people who will want to view it or send people to do so in their stead. Chances are you will have to show the damage to representatives for the construction company, their insurer's adjuster, the sponsor of the work (usually a governmental organization) and their insurer's adjuster, one or more engineers and your attorney, if you retain one, at least. This can become very time-consuming, if there are many damage sites on your property. But, it is to your advantage to have the damage as well-documented by as many viewers as possible.

As this parade of people goes on, neighbors may start to ask about the reason for it. You may then feel a need to show them the damage as well. If so, confine any comments you make to the damage itself. You can expect such viewings to continue occasionally for pretty much the life of your claim.

You should be both thorough and forthcoming in showing the damage you believe was caused by construction-induced ground vibration. **Be careful in what you say** about its cause or any other circumstances not relating directly to the damage. Make sure that you **cover every type and location of damage** of which you're aware, both inside and outside. Don't try to simplify it or save the inspector time by glossing over some of it. If the person inspecting the home doesn't see everything or doesn't care to do so, that should be their responsibility, not yours. If you haven't fully surveyed or presented the damage, state that fact to any person who views it.

Exercising Control Over Inspection Visits

Most viewers of the damage will take **photos and/or videotape** of their visit to the home. You must always keep in mind that **these visitors are looking after their or their company's interests, not yours**. You don't want to allow these visits to turn into "fishing expeditions", where photos are taken of your dirty laundry, over-full closets or other items unrelated to damage which might be used against you. Along those lines, the house should be reasonably clean and uncluttered, to the extent that an acceptable amount of effort can bring that about. Unless you have damage in them, close doors to closets and rooms which are not in use.

One way to gain some control over what records are created in these visits is to prepare a document for signature by all visitors which **limits what can be recorded** and preserves

your right to a true copy of any photos or video taken. An example of such a document, used by me, is available here. If you have created a video or photographic record of any sort, and you wish to provide it to those who view the damage, it is wise to keep a record of who obtains that video. Another document, on the same page as the conditions document, is a **receipt for any video or photos** you may provide to visitors. We found these signed documents useful when various opposing "experts" and adjusters "lost" or simply refused to produce their photos and video. If you have retained an attorney before such visits begin, check this matter out with him/her.

Meetings, Phone Calls, Conversations

From personal experience, I would say that it is a good idea to **videotape every meeting** you attend which deals with the damage or construction. This includes visits by "experts", especially those hired by the construction company, to view your damage. Chances are good that you will wish you had videotaped such meetings and visits, if you don't do so. Exact times of incoming calls are easily gotten from Caller ID, if you have it. Use it to get the information before it is pushed out of memory by later calls. These should go into your timeline narrative at the appropriate locations and dates.

If You Sue

Filing suit will multiply the time demands several times over. You will have interrogatories to answer, production requests to fulfill, and meetings with your attorney to attend. If you can't reach a settlement after the filing, you'll probably have to attend depositions (yours and others) and help the attorney get ready for them to the extent that you can and the extent that he wants help. More information on the legal process can be found on our pages, Involving an Attorney and Litigating.

Involving an Attorney

Filing a lawsuit should be your option of last resort in addressing your legitimate vibration damage claim. Amicable resolution with the construction contractor is the best approach. If that fails, most jurisdictions either encourage or require mediation (see CVDG Pro page, Settlement for more information) prior to a trial. You will need an attorney for the mediation, but the costs for that are minimal, compared to the cost of a full-blown lawsuit. You may not have any option regarding an attorney, if the construction company or their insurer involves an attorney. Following are some considerations in choosing and using an attorney. For some information regarding what to expect in the litigation process, see the CVDG page Litigating.

Should You Retain an Attorney?

You can easily run up $200,000 or more in legal costs (attorney fees, expert witness fees, deposition transcripts, court fees, etc) to pursue a construction damage claim through trial to verdict. You can still lose at trial, often for reasons which have nothing to do with the extent of your damage, the legitimacy of your claim, the strength of your evidence or the performance of your witnesses and attorney at trial. A "relatively small" claim under $10,000 or so cannot justify the cost, let alone the irritation, of litigation. If your claim is significantly larger, you may want to talk with an attorney. He can help you understand the environment for litigation in your area, evaluate your claim and estimate its likelihood of success in a lawsuit in your jurisdiction.

Because construction companies are sued with some frequency regarding damage claims, they or their insurers have experienced legal teams to defend against such claims. This is one reason why you may have difficulty finding an attorney who will take a vibration damage case on a **contingency basis** (i.e. where you only pay "costs", not attorney fees, unless you win a settlement or at trial). Thus, you may have to pay the legal costs from your own pocket. **If you don't have that kind of money, justice may not only be delayed, but denied**. **Construction firms and their insurers assume that they can run out your funds** and will do just about anything to stretch out the course of a lawsuit in pursuit of that goal.

In a case taken on contingency, you still have to pay the attorney's "expenses" (expert fees and costs, court filing costs, supplies, etc.), which can easily run to $50,000 or more in some cases. Even if you win a case taken on contingency, the combination of the attorney's fraction of the judgment, plus the costs, could wind up with him taking more than half the award. Winning plaintiffs in contingency suits sometimes end up suing their own attorneys, because the attorney's share ends up being more than the plaintiff's.

When to Get an Attorney

You may find that the decision to get an attorney will be made for you. The contractor or their insurer may involve their attorney immediately in an effort to intimidate you. You can proceed for a short time without a formal retention agreement with your attorney,

but it is wise to begin talking with one the moment that you learn the opposing side is using an attorney. That way, you can get some basic advice on handling interactions with the opposing side (CVDG Pro) until you become convinced that retaining the attorney is necessary. Another reason to involve an attorney might be to protect critical documents which you have prepared from production to the other side in the discovery phase of a lawsuit. Just about anything prepared for your attorney is protected by "attorney-client privilege" and is generally not subject to production or questioning.

Even if the contractor doesn't involve an attorney, you may find it necessary to get one in order to have your claim taken seriously. You may get the sense that the contractor or insurer simply wants to view the damage and talk with you to help prepare their defense, rather than trying to resolve the issue with you. If so, it is probably time to talk to an attorney about your claim. **Keep in mind that there are often statutory limitations on the length of time after the damage is done that you have to file a tort (i.e. civil) claim notice with the contractor and, especially, with any responsible governmental entities.** You should discuss with an attorney what these are in your jurisdiction, so that you don't lose your rights to file a claim.

Also recognize that governmental entities are protected to a greater or lesser degree in various jurisdictions under the "**sovereign immunity**" doctrine. Usually, state laws set the conditions under which you can sue the state or a municipality in that state. Often, **states and municipalities will invoke sovereign immunity to avoid liability**. This issue will be decided by a judge, not a jury, since it is a matter of law, not fact.

Should Your Case Be a Class Action?

If a large number of other homeowners in the area of the construction have documented damage connected to the construction, as was the case in the example with which I'm most familiar, you might be inclined to consider a "class action". Class actions are sometimes referred to as "welfare for attorneys", because the attorneys can make many millions of dollars, the named plaintiffs a little money and everyone else in the class virtually nothing. Class actions take much longer to resolve than individual actions and must be certified by the Court, lengthening the time to resolution. In general, you will need an attorney with class action experience, in addition to vibration damage claim experience. In my view, a class action is not a good idea for most homeowners with construction damage, for these and many other reasons which I will not try to document here. If you believe a class action is something you might want to pursue, talk with your attorney at some length before you move forward. If you want to share attorney costs with others in your area who have damage, you can all be named as plaintiffs in a lawsuit, without the need for a class action.

Choosing an Attorney

Ideally, you would choose an attorney who has knowledge and experience in pursuing ground vibration-related construction claims and some acquaintance with the likely counterarguments (CVDG Pro). Unfortunately, such attorneys are not commonly available anywhere. You can use the Internet to find attorneys with that experience and knowledge; if you're lucky, one of those can try cases in your jurisdiction. Of course, you can bring one in from out of state, but that will increase your costs accordingly. Further, unless you have scientific background that would allow you to **educate a local attorney**

yourself on the scientific and technical issues, you will have to pay an expert to do that same job, just to get the attorney ready for depositions and trial. The CVDG, in either the free or Professional Edition, should help you and the attorney in that process.

One very important question you should ask when interviewing an attorney is whether or not he/she has any **conflicts of interest** in pursuing a claim against the construction company and/or the sponsor of the work. Potential conflicts of interest are common, especially in smaller cities and towns, since a qualified attorney may have worked with or know some or all of the people on the other side. **The attorney should tell you about possible conflicts without prompting, but don't leave it to chance**. Note that any prior acquaintance or work with the opposite side is not, necessarily, a matter for disqualification. If the attorney indicates a conflict of interest or the appearance of one, ask for more details so that you can judge whether the attorney's conflict is something that would affect your situation.

If you have to go to trial, you will be working with the attorney for years, so choosing one you respect and can work with well is important. Be especially careful if the attorney intimates, or says outright, that he isn't used to clients taking a personal interest and role in their cases. An attorney who takes this view, **perhaps** excepting if he is one of the handful of attorneys who have real experience in vibration damage cases, will probably do a poor job for you. My personal view is that you **don't** want an attorney who has **too** much of the fighter in him, despite what legal ads on TV might lead you to believe. Fighting instinct can be good, but may not be so constructive in finding a fair settlement. **Choose an attorney who is smart, willing to learn, has a good reputation in your community for honesty and integrity, and believes in you and your case**. Such an attorney will fight for you, but will not turn every issue into an unnecessary fight.

Don't be too concerned about differences in hourly rate quotes from attorney to attorney. A knowledgeable attorney can do things faster with less preparation than one with no specific knowledge of vibration damage claims. The "higher priced" attorney may actually save you money in the long run, if he has real knowledge and experience in the area.

Communicating with the Opposing Side

You should **never** speak with the opposing attorney or representatives of the construction firm without your own representation either present or aware that such a conversation is taking place. **Never** participate in a meeting, nor allow an opposing attorney to be present at any such meeting, without representation of your own present or aware of the meeting. **Never** allow an opposing attorney to visit your damaged home for any reason, without the presence of your own attorney during the visit.

Keep in mind always that, even if the contractor or its insurance company seems friendly and receptive to your claim, **you have no friends in the opposition**. You should be honest, friendly and reasonably open about your claim with the contractor or its representatives, but **don't volunteer any unnecessary information**. To appropriate a familiar caution, "Anything you say can, and will, be used against you in a court of law." **If you have retained an attorney, follow his/her advice to the letter** with regard to communications with the opposing side. Once you are formally represented, the opposing side should be precluded from contacting you other than through your attorney. For more

on interacting with others regarding a claim, see the CVDG Pro page, Handling A Claim.

Working with the Attorney

Let the attorney do what he/she does best and **follow her/his legal advice**. Make certain that he understands the case as well as you do, even though it may take a while to accomplish that goal. Don't assume that, because you have an attorney, he/she can or will think through every possible avenue in carrying the case forward. If you have some suggestions, make them. If the attorney doesn't want to follow them, ask for an explanation that you can understand. **Find, provide, understand and explain whatever supporting documentation and/or relevant scientific work that you can**. Doing so will save you money.

If you're married, **make sure that your spouse understands the case as well as you**. Your spouse likely will be deposed in litigation, or, at the least, asked questions at trial, and can hurt the case if he or she makes mistakes through lack of knowledge. As a general rule, the more minds and approaches that you can bring to bear on the case, the better your chances, so **use all the human resources available to you**.

In dealing with an attorney, keep in mind that **his time means your money**! Cases move slowly through the legal system. In most cases, you need not and will not hear from the attorney every week. Call the attorney only when necessary and have a list of topics prepared for the conversation so that you don't waste his time or yours. E-mail can be extremely helpful in communicating with your attorney, because you can use it to give him information, ask questions and send PDF-format documents without making trips to the office. E-mail also provides documentation and uses a minimum of the attorney's time. Your e-mails to the attorney should be just as concise and to the point as your conversations with him. The CVDG Pro page, Working With An Attorney, has much more information on how you can interact with your attorney most effectively, so as to save you considerable money in attorney fees.

Finally, always remember that **your case is not the only one** the attorney is working on at any given time. Expect the attorney to forget facts or fail to understand some matters on the first recitation. Be patient and willing to repeat things until they are understood. **Remember, if a smart attorney has difficulty grasping what you're saying, a jury likely will have difficulty, too.**

If your claim is large enough, you may well find yourself in a trial or preparing for one. You will want to think about and talk through with an attorney whether or not you have the determination, financial ability and case strength to persist through that process. You will find that **your best friends throughout litigation are your knowledge, honesty, personal integrity, and determination**. They will serve you well if you keep them uppermost in your mind.

Litigating

Litigating a Vibration Damage Claim

Litigating is time-consuming, expensive and frustrating, but may be your only option if you have substantial vibration damage. It can easily take years to get your case to trial. You may have to take the lead role in assembling the case, probably educating the attorney in the process. You will have to participate in (and pay for) depositions in the case. Expert witnesses will have to be located and you will have to pay for their time and travel, even if you find an attorney who will take your case on a contingency basis. The more parts of the case that you can do, the more money you can save in legal costs, so expect to spend a sizable amount of your own time assembling the facts and documentation (see the CVDG Pro document, Researching A Claim, for more on this topic) for the case. This page has basic information about the litigation process, for those who may be unfamiliar with it.

Damages

There are two basic types of damages that you can seek in a "**tort**" (i.e. a civil wrong, not criminal charge) claim, **compensatory and punitive damages**. **Compensatory** damages are those that can be granted to reimburse you for your monetary loss. You will have to document that loss thoroughly with repair and other estimates. Even if you have documented the loss well, it can be expected that the construction company, their insurer, or their attorney will do everything in their power to minimize or call into question part or all of your compensatory damages claim.

Punitive damages are separate from compensatory damages and can be awarded by a jury over and above compensatory damages. While I'm not an attorney, a layman's way of describing punitive damages is that they can be awarded only if the jury finds the defendant to have acted in a willful, disregardful, fraudulent, unlawful or reckless manner (or, in some cases, all of the foregoing). An attorney in your jurisdiction would probably include some other, or different, descriptions as well. Thus, you can receive compensatory damages and not be awarded punitive damages. In most situations, you cannot be repaid for the time you invest in keeping down your legal fees nor can you obtain reimbursement of legal fees themselves. Punitive damages are about the only way you can get these items covered, at least in effect.

The Tort Claim Notice

In most jurisdictions, your attorney must file a tort claim notice, or similarly named document, with the prospective Defendant(s). Your own written notification of the Defendant(s) of the damage and its presumed cause is **not** a replacement for the tort claim notice. The notice allows the Defendant(s) to learn of the claim and obtain or notify legal counsel. The tort claim notice should be filed by your attorney as soon after

you become aware of the damage as is practical. There can be a considerable period of time between the filing of the tort claim notice and the filing of the actual lawsuit. This time is often used by the attorneys for the parties to attempt to work out some reasonable settlement of the claim, thereby saving the time, expense and frustration of litigation for both parties.

Filing Suit

Damages can be awarded at trial only after you have established that the Defendant was guilty of one or more **causes of action** named in your lawsuit. Causes of action are violations of law, propriety, normal concern, accepted procedure or contract terms (among others), which you can show contributed to or caused your damage. These are stated in your lawsuit as reasons for the suit, along with facts supporting the causes of action.

The lawsuit itself is usually written by your attorney. That said, you will have to provide the attorney with a great deal of factual information to support the drafting of the suit. Once the suit is drafted, you must read it carefully, making any changes to wording that you think are necessary to state correctly the facts. This is critical, because you understand the facts better than the attorney, even though you probably don't know the law as well as he/she does. You will have to live with every word in the lawsuit, so **make certain the lawsuit is factually correct in every detail**. In reading it, you may also identify possible causes of action that have been omitted. You should discuss any of these you may find with the attorney.

Discovery

Discovery is a process by which each side finds out about the available facts in the lawsuit, after it has been filed. Discovery is time-consuming and expensive, but it can be helpful in resolving the suit before the expense of a trial. It is done through **interrogatories** (questions asked in writing to the opposing side and answered in writing under penalty of perjury), **productions** (providing requested copies of relevant documents, media and other potential evidence to the opposition), **admissions** (asking the opposing side in writing to admit certain facts to establish those factual areas which are not in dispute) and **depositions** (pre-trial testimony "on the record" to questions asked by the opposing attorney). Both sides carry out discovery, and it includes not only the litigants, but, in most jurisdictions, any expert witnesses (see below) who may be called to testify by the litigants. There are often multiple iterations of each of these processes in the course of a lawsuit. Filing the first set of discovery requests with the suit is often wise, as a means of showing that the suit is serious in intent.

Because vibration damage claims have many technical aspects, discovery in such cases must be done thoughtfully and thoroughly. Since discovery requests are usually compiled by the attorney, I will not include a listing of their likely contents here. The attorney should probably **enlist the aid of an expert** early in preparing interrogatories, production requests, admissions and deposition outlines, especially if the attorney has limited experience in such cases. The homeowner plaintiff should **review discovery requests** for completeness. Our *CVDG Professional* page, Production Requests, has a long listing of the scientific and technical requests that a plaintiff in a vibration damage suit should consider making to a defendant contractor and/or the sponsor of the work.

Commonly, one or both of the sides make discovery demands that are well beyond the bounds of the lawsuit facts. This is often referred to colloquially as **a "fishing expedition"**. It is just as common to refuse some unreasonable, irrelevant, or even unsafe, discovery demands (for example, requests for your Social Security number). Talk with your attorney if you feel some requests to be "overly burdensome" or irrelevant **before** you respond to them.

Just as you may refuse some requests, the opposing side likely will refuse some of yours for good, or bad, reasons. If the information sought is both relevant and critical, e.g. clearly missing vibration monitoring data and reports, and you cannot get them after multiple requests, you can file a **Motion to Compel** with the Court to force production of those items. If they turn up missing or destroyed after the Court rules in your favor in such a Motion, you can seek to have all that **testimony and evidence excluded** at trial and/or seek **sanctions** against the opposing side. If the evidence sought is important to both sides and hasn't been produced, **don't assume that it simply can't be gotten**; don't be afraid to fight to get it produced.

Witnesses

You and your attorney will need to **identify potential witnesses** in the case during discovery. These fall into two basic classes, **fact witnesses and expert witnesses**. **Fact witnesses** give testimony on the facts surrounding the case; they are not permitted to speculate or guess, give opinions, or relate information outside their personal knowledge and observation. Typically, a plaintiff will appear in the case as a fact witness. Other fact witnesses in a vibration damage case might include neighbors who observed the work or who have damage themselves, representatives of firms who have provided estimates for repair, and employees of the construction company, among others.

About Expert Witnesses

In essentially any litigation in which scientific or engineering issues appear, including vibration damage litigation, there will also be **expert witnesses** on both sides. Ideally, expert witnesses are people who, by training, education and experience, are qualified to offer **knowledgeable** scientific and engineering **opinions** that help to explain the case facts. **Scientific experts** will usually have a Ph.D. in a scientific discipline, plus relevant experience and/or training. A qualified scientific expert should have a **significant record of publication in the peer-reviewed scientific literature** (i.e. say, more than 10 publications), perhaps including a book or books. Ph.D. engineers are relatively rare, so an **expert engineer** may not have a Ph.D., but should have relevant experience and/or training, as well as publications in the peer-reviewed literature of his field. Your attorney will usually identify possible expert witnesses, though you can help if you are aware of some possible ones.

An honest, hard-working, forthright, strong and knowledgeable expert witness can be a great resource for you and the attorney in understanding scientific issues, preparing interrogatories and production requests, and getting the attorney ready for deposition and trial. His knowledge, if he can communicate it well, can actually save you money by reducing the attorney fees, even though you are paying the expert. A **good** expert can also be a huge help in pointing out weaknesses in and potential counterarguments to your case, at least in his area of expertise. A **bad** expert can do more harm than good for you,

even if he toes your line to the letter. Chances are he'll cost you just as much or more money than a good one.

There are many people these days who may look like "experts" on paper and who may have expert witness experience. But, if you find they are reluctant to do actual work, have trouble understanding important elements of your case in their area of expertise, won't think about your case outside meetings with them, or simply seem untrustworthy, you should shy away from them. Just as importantly, an expert who is unwilling to disagree with you on scientific grounds, when he thinks you're wrong on some aspect of the case in his area of expertise, likely will not stand up to cross-examination by the opposing attorney.

You should **be an active participant** in meeting, talking with, and making a final decision whether or not you'll use a particular expert in your case. Make your decision based on whether the expert shows honesty, candidness, expert level knowledge as applicable in your case, a willingness to stand strong in supporting his opinions and an ability to help you and your attorney prepare the case, not necessarily simply on whether he appears to agree with you in every aspect. You should also consider how a non-technically trained jury might react to the personality of the expert, if your case goes to trial.

Giving Testimony in Deposition and Trial

Giving testimony, either at trial or in deposition, cannot be described as "fun" or "easy" - a fact well known to me from a great deal of experience as a scientific expert and as a plaintiff in a vibration damage case. However, you need not fear the prospect of testifying. Your attorney will help prepare you to give testimony, both in deposition and trial. **Listen to and follow his advice**. **Prepare yourself well on the facts, so that you can give testimony with confidence and accuracy**. Giving strong testimony is both an art and a science. For more information on this topic, see the CVDG Pro page, Giving Testimony.

Trial

Trial is the culmination of those few cases which cannot be settled, usually because the damages are extensive and expensive to fix. Every trial has its own dynamics, largely dictated by the facts of the case. One of the most important trial-related events actually occurs before the start of trial in a so-called **"motions** *in limine"* **hearing**. Prior to this hearing, each side files motions (requests) with the Court to limit (that's the Latin *in limine* part*)* what testimony can be heard by the jury and/or what witnesses can testify. Usually, each side also files a response to the opposing side's *motions in limine*. The judge makes legal, not factual, decisions on what evidence gets into the trial and what stays out. The content of the evidence the jury gets to hear often determines the outcome of the trial, so considerable thought and work should go into preparing for these hearings, both on your part and that of your attorney.

Choosing a jury (a long topic in itself), is as much an art as a science. There are many jury consultant firms across the country who will give advice on how to choose jury members from the pool picked for a trial by the jurisdiction. In the end, your attorney will have the best understanding of the people and the jurisdiction. However, you, and he/she, should keep in mind the prevalence of "construction can't cause vibration damage" biases among those involved in the construction and allied industries. It may be

wise to use peremptory challenges to excuse those prospective jurors who express such biases in the pre-trial juror interviews and, if possible, prevent other potential jurors from hearing such biased opinions.

Once the jury is chosen, the trial starts. The course of trials is determined by many factors, usually individual to each case. Plaintiff(s) present their case first and have the burden of proof. The standard of proof is **a "more likely than not" standard in civil litigation**, compared to the "beyond a reasonable doubt" or similar standard in criminal cases.

One thing that homeowners with vibration damage should keep in mind is that **all trials have ebbs and flows and changes in "momentum"**. If you or one of your witnesses does less well than you expect, **don't get upset, especially in front of the jury**. Move on and, through the vehicle of your attorney's questions, present your case undeterred. Things which seem bad to you may not have been understood or simply completely missed by the jury. If you become upset by such things, you are, in effect, pointing out to the jury something to which they might have paid little attention. Your attorney will make whatever "repairs" are necessitated by the performance of any witness.

Expect that the opposing attorney will make some minor progress against you and your witnesses in cross-examination. He has had years to prepare. **If all else fails, he can simply misrepresent the evidence during cross and close**. If that last statement sounds cynical, it is based on actual observation of many attorneys over the years in quite different types of cases, both as a scientific expert witness and as a plaintiff. That prospect means that you and the other witnesses must **be alert to the possibility that some of the representations made to you in questioning by the opposing attorney are literally false**. Prepare well and point out those misrepresentations, if necessary. **Try not to react in front of the jury to testimony of other witnesses which you believe to be false, in error, or misrepresentative of facts.** Your attorney will have a chance in cross to challenge such testimony. You can, and probably should, take notes during the trial regarding issues that come up that you might want your attorney to cover.

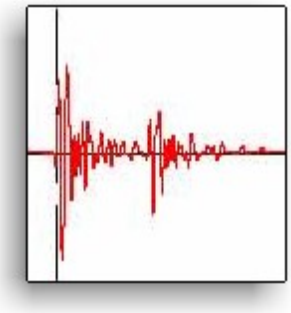
For those who haven't been through it, trial is incredibly intense and draining on all parties. The attorneys will often be working every night, sometimes through the night, preparing witness testimony scripts or cross outlines and meeting with the witnesses to go over direct exam scripts. You may have to prepare trial exhibits on short notice or answer questions late into the night, losing sleep yourself. In this environment, it is understandable if people get short-tempered and say things they wouldn't normally say. If that happens, write it off to the intensity of the situation and the stakes involved. **Try not to get offended or hurt. Be as cooperative with requests from your attorney as you can**. Most trial teams have more than one attorney on each side; cooperate as much with your attorney's colleagues as you would with him/her.

Throughout the trial, try not to "bug" your attorney unnecessarily, but don't hesitate to help him with facts during breaks. On really important factual matters, you can send him an occasional note during testimony. Although some might disagree with this advice, I think that you should **let the attorney run the case** as he sees fit at trial. He may make some decisions that you might question, but he has probably thought through the implications of each piece of testimony and evidence, where you may not have done so. If you feel strongly about some issue, bring it up in a break, at lunch or after court.

This "brief" description can't do justice to all the dynamics of litigation generally or to the specifics of vibration damage litigation. The intention of it is to familiarize homeowners with some of the workings of the litigation process, based on my over twenty years of experience and over 50 occasions giving sworn testimony, both as a scientific expert and fact witness. If the advice of your attorney contradicts anything said here, **follow your attorney's advice and counsel**.

Disclaimer: The Construction Vibration Damage Guide is not offered, and should not be considered, as advice on the law in any jurisdiction or form. Seek the advice of an attorney with construction vibration damage claim experience and knowledge, if you need legal help. Trademarks appearing in the CVDG are the properties of their respective owners and are used in the CVDG only for the purpose of identification.

Vibration Monitoring



Vibration monitoring is the most commonly used method for identifying potential vibration damage problems pre-construction and addressing them post-construction. Most Federally-funded construction projects require pre-construction vibration assessment. Individual states and municipalities may require no monitoring or monitoring only in connection with blasting done during the project.

Properly done, vibration monitoring can be extremely helpful in understanding the nature of your damage and whether construction could have caused it. Improperly done, it can be worse than worthless. Since construction companies will sometimes present to those with damage claims copies of vibration monitoring data or reports, this page will offer an overview of vibration monitoring and what can be learned from it.

Vibration Monitoring Instrumentation

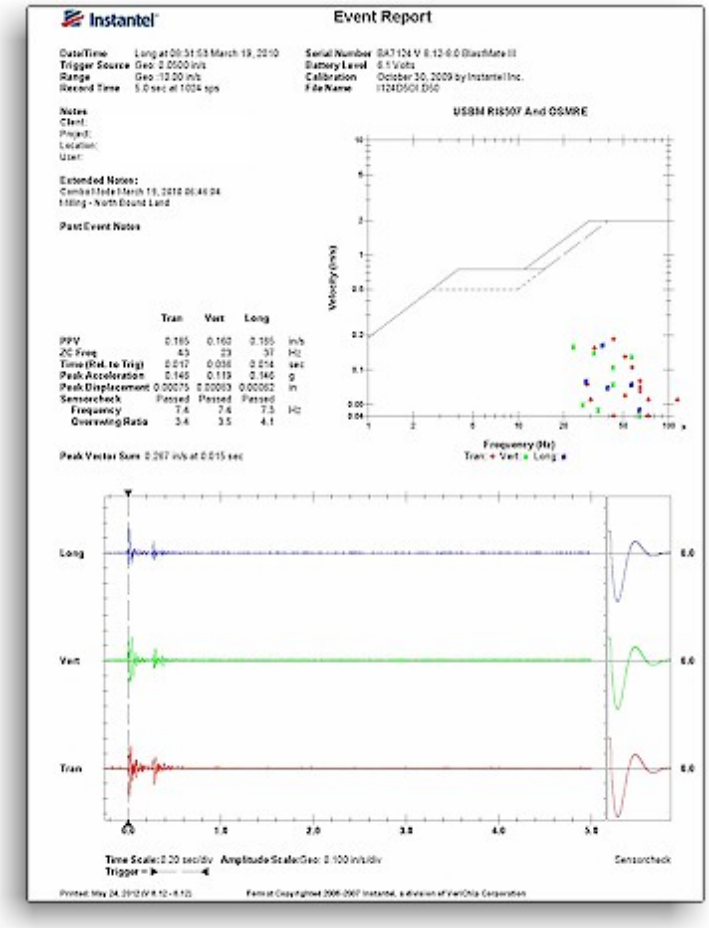
A number of manufacturers make ground vibration monitoring seismographs, primarily for use in monitoring mine blasting, although they are also routinely used in construction vibration monitoring. Like earthquake seismographs, these detect and measure ground vibration by the movement of a magnet surrounded by a coil of wire. According to the **Lenz Law** of physics, a current is induced in the surrounding coil in proportion to speed of movement of the magnet with respect to the coil (i.e. the speed of ground movement). Electronics in the monitor then measure this current, convert it to ground motion velocities and store the raw data in memory. Each of the three directions at right angles to each other (longitudinal or radial, transverse, and vertical) has its own separate measuring coil in the transducer head, since vibrations often differ in important ways along different measurement directions. **For accurate measurements to be obtained, the seismograph measuring head ("transducer") must move as the ground moves, i.e. it must have full "ground coupling".**

At right is a photo of a Blastmate III blasting seismograph[1], manufactured by Instantel, in use. The silver gray transducer head at the lower right of the photo, which does the measuring, is sitting on top of the loose landscape rock and connected by the visible wire to the blue recording box. The blue box actually stores the data in its memory, much like a small computer. This instrument can also keep a paper tape backup record of the data as it is created, using its integrated printer on the left side of the blue control box. Although not seen in this

example, blasting seismographs usually also have a microphone attachment which can be used to measure sound from the operations. **This photo should not be taken as showing a proper installation of the seismograph, as there are numerous problems in this installation which contradict Operator's Manual instructions and other guidelines set by industry and government groups.**

Other kinds of instrumentation can also be used to detect and measure ground vibration and its effects on structures. These include accelerometers and displacement gauges. They provide different, but complementary, information to that provided by seismographs. While these other equipment types are used in scientific studies, they are rarely seen in construction or blasting site vibration monitoring nor are their measured properties considered the best indicators of damage potential. Recent advancements in technology of cell phones and tablet computers, along with development of several software programs to access them, have made it possible for homeowners to do their own vibration monitoring at very reasonable cost. The topics in this paragraph are discussed on the pages, DIY Monitoring and Vibration Measures, available only in the free CVDG PDF download and in the CVDG Professional Edition, not online.

Handling of Vibration Data



Once recorded, the vibration technician downloads the data stored in the seismograph memory to a personal computer for printing and analysis with appropriate software. In the case of the Blastmate III, the software for Windows® is called *Blastware*, and can be obtained free from Instantel. Other manufacturers of seismographs make similar software available for their products. Once the data are in the computer, the software can display those data in various "reports" (see at left for one such report type), similar to database program reports, that show them in different, complementary ways. Although the reports generated by software from the manufacturers of different seismographs will differ in both name and content, they will mostly show the same data in much the same way.

Reading Vibration Monitoring Results

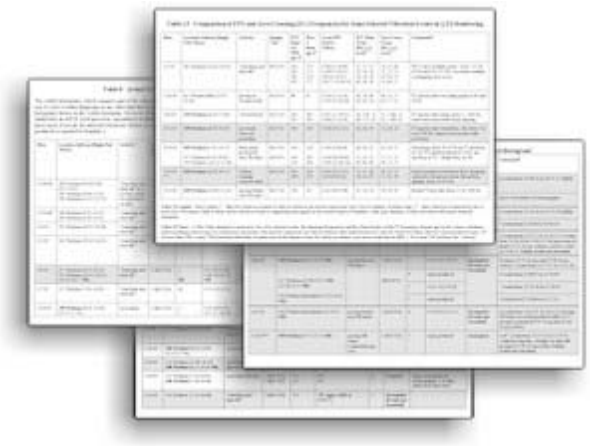
Construction companies and the vibration monitoring subcontractors they hire have a vested monetary interest in finding that vibrations are non-damaging to structures. Some may also be ill-prepared to understand the real meaning of vibration monitoring results. For these and other reasons, **you may be the only person involved in a vibration**

damage claim who will take the time to read and analyze vibration monitoring results carefully. You should make time to do so, or, better yet, ask a qualified scientist to read and analyze them for you. Some of the problems you should look for are detailed on the CVDG Pro Vibration Data Issues page.

Extensive additional information on vibration monitoring, report reading and analysis, interpretation and standards can be found in the *Construction Vibration Damage Guide, Professional Edition*.

Analysis and Interpretation of Vibration Monitoring Data

Proper and careful analysis of vibration data is laborious and time-consuming, but essential. At right are shown just four of the over 50 pages of tables which I prepared, relating to the detailed analysis of a partial set of vibration data for one road reconstruction project. Each table looks at the same data in different ways and provides a view and analysis of different elements of the data. Virtually all of these views proved important in understanding what the data really said, versus what was claimed by the construction contractor and its vibration monitoring sub-contractor.

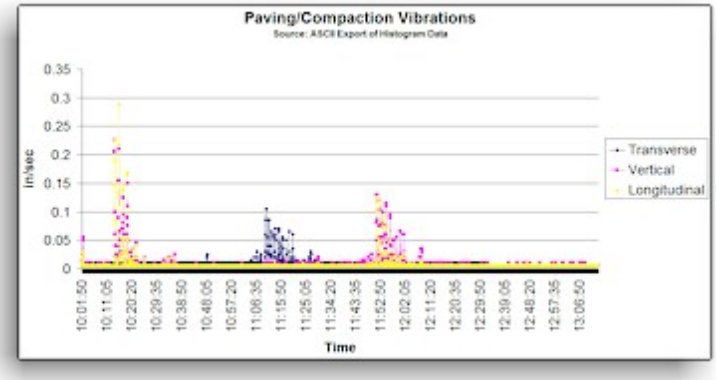


For meaningful conclusions to be drawn from vibration data, they have to be properly obtained (i.e. following seismograph manufacturer and industry group instructions), analyzed and interpreted. All the data must be used, not just carefully selected parts, and they must form a consistent picture. Otherwise, the conclusions can have little or no scientific validity.

This is such an important and large area that many pages in the CVDG Professional Edition are devoted to various aspects of vibration data acquisition, handling and interpretation. For help in reading and understanding vibration monitoring data, read the *CVDG Pro* page, Vibration Data Reports. For more on possible problems to look for in analyzing the data, see its page, Vibration Data Issues. The *CVDG Pro* page, Vibration Data Analysis, has a much longer and more detailed listing of specific vibration monitoring issues. For detailed tips in analyzing the large amounts of vibration data generated in monitoring, see our *CVDG Professional* page, Vibration Data Handling.

Standards and Their Proper Use

Even if vibration monitoring data can be read and understood, they won't be of much value in the absence of some independent, accepted means of linking them to the potential for causing damage. Because the mining industry has faced vibration damage claims for many years related to **blasting activities**, most of the data on structural effects of vibration, and standards for interpreting vibration data in that light, are based on **studies done by or for the mining industry**. Unfortunately, these blasting related studies and standards, while often used by construction companies and state agencies to justify their positions, provide little help in evaluating the potential for damage from construction vibration caused by heavy equipment.



Fundamentally, the reason for this is that **blasting events differ dramatically from construction vibration**. Blasting at a typical mine or quarry occurs perhaps once every day to every few days; it produces vibrations which last a few seconds at most (more typically, less than one second for the direct blast vibration). On the other hand, construction vibrations can go on for minutes, hours, days or even months. The diagram at right shows one of many examples where **construction vibration repeatedly occurred and persisted at levels above the FTA standards for minutes at a time**. This difference brings into play resonance effects and amplification phenomena which are far less prominent or completely absent in most blasting environments.

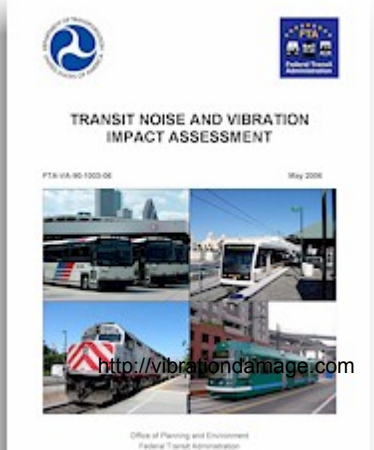
This fundamental distinction between blasting events ("shots") and construction vibration is explicitly acknowledged in USBM RI 8507, the basis for the frequently used OSM blasting standard:

> *"The damage probabilities realistically refer to numbers of homes being affected by a given shot rather than the number of shots required to damage a single home."*[3]
>
> *"Safe vibration levels for blasting are given in Table 13, being defined as levels unlikely to produce interior cracking or other damage in residences. Implicit in these values are assumptions that the structures are sited on a firm foundation, do not exceed 2 stories, and have the dimensions of typical residences, and that the vibration wavetrains are not longer than a few seconds."*[4] *(emphasis added)*

Thus, **use of blasting standards for non-blasting, long-lived construction vibrations is ill-advised and scientifically questionable**. Of course, even well-motivated contractors may simply not think about or understand these disparities. This is a long and important topic which is investigated further on the CVDG page, Vibration Standards.

Distance Makes the Vibration Become Lesser, But....

Vibrations die off with distance, although perhaps not as fast as most people would think. The lessening intensity with distance is the rationale behind what are called **"scaled distance" calculations** accepted and used by the mining industry to estimate vibration effects at distances other than those measured. The Federal Transit Administration's *Noise and Vibration Manual* (formally titled *TRANSIT NOISE AND VIBRATION IMPACT ASSESSMENT*) also provides a version of a **"scaled distance" equation** and necessary parameters for that equation to calculate expected vibration intensities at various distances from different types of standard construction operations[5]. This equation may be useful when no vibration data exist, but damage is done.



Users of the equation should note that the benchmark vibration velocities for **appropriate** uses of construction equipment given in that reference are indicated to be representative, not characteristic, of all such pieces of equipment or all methods of use of the equipment. Improper use or use of different equipment than that indicated in the standard could produce larger or lesser vibrations. You will need distances from your home to the vibration sources for use in this equation. You can either measure them or use Google Earth's Ruler feature[6] to get them from satellite photos of your home and its surrounding area.

Simple distance-based calculations do not tell the whole story of damage potential. As vibrations propagate through the ground, their frequency distribution changes from a typical broad spread of high and low frequencies to what are referred to as "**low frequency wave trains**" (see USBM RI 8507[2]):

> "*Thick soil overburden as well as long absolute (as opposed to scaled) distances create long-duration, low-frequency wave trains. This increases the response and damage potential of nearby structures.*"

The frequency of the vibration wave trains is close to the resonance frequency of the house. At the resonance frequency, vibrations in the house grow with additional vibrations, rather than dying out. Thus, distant vibrations with resonant components can be more damaging than vibrations which originate nearby, especially when they last for longer than a few seconds, as is typical in construction vibration. Vibrations which may not be damaging close to the site of their inception, may become damaging at larger distances (typically, a few hundred yards for blasting vibrations), even though they are less intense at the greater distance.

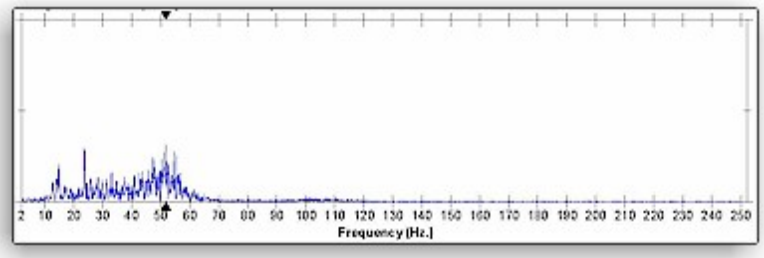
For that reason, **having your house at some distance from the work may not guarantee vibration damage safety** nor can distance always be used as a legitimate scientific argument against damage causation. In our own case, the largest single crack that we observed developed when the construction work was a block away, although the cracks and other damage became more numerous and widespread as work approached the house. **As a rough guide, if you can hear the construction operations in the distance, there might be reason to be concerned**, depending on what operations are being carried out and how they are being done. The effect of distance in vibration damage is discussed further on the CVDG Pro page, Applying Vibration Standards.

Locating and Using Blasting Seismographs

Vibrations spread out in all directions from the source, but usually not equally so, for reasons discussed on the CVDG page, Vibration 101. Because the frequency distribution, intensity and interaction of vibrations with structures depend so strongly on distance, a good vibration monitoring program will include more than a single seismograph, each well-located, calibrated and properly installed. Thus, a good vibration monitoring program will use two or more seismographs in tandem, one placed near the source of the vibration and one placed, perhaps, a hundred yards away. The second seismograph should be placed to avoid interference from vibrations from any additional operations going on at the same time as those producing the source vibrations. Of course, the intensity (velocity) of vibrations at the distant seismograph will be lower, in the absence of

vibrations from other operations, but the point of the second seismograph is to **detect and quantify the low frequency wavetrains[2]**, as discussed above. Their frequency distribution and duration are at least as important as their measured velocities (PPV's).

Vibration Monitoring Data Reporting



It is pretty much standard in the field of vibration monitoring simply to quote the maximum PPV observed for a given time period, location or operation, with, perhaps, a single **"zero crossing frequency"** (a simple approximation of the frequency of the largest component) for the quoted vibration. While this simplistic approach may seem adequate to some, it has little scientific meaning or validity in the context of assessing potential for damage. As discussed on several of the CVDG pages, including Vibration Standards and Resonance and Fatigue, damage potential is dependent on both the maximum velocity of the vibration and its frequency distribution. Many types of construction vibration, particularly those resulting from impact or impact-like events, have broad frequency distribution spectra (see tracked excavator drive-by vibration spectrum at right above), which show significant intensity at the resonant frequencies of homes, even if the peak frequency of the vibration is not of any special concern. Such vibrations cannot be adequately or appropriately described by a single PPV at a single frequency.

Thus, **simple quotations of PPV's, even if accompanied by the zero crossing frequency, can be misleading and are of little value in estimating damage potential.** One must take into account the complete frequency spectrum of the vibration, as derived from FFT analysis. Sadly, most vibration data are reported as single frequency PPV's, lacking any spectral analysis whatsoever. In all too many cases, FFT analysis of the frequency composition is not even possible, due to early filling of the seismograph event memory with waveform data. This issue is further explained and developed, with actual construction vibration examples, in the CVDG Pro pages, Reporting Vibration Data and Vibration Signatures.

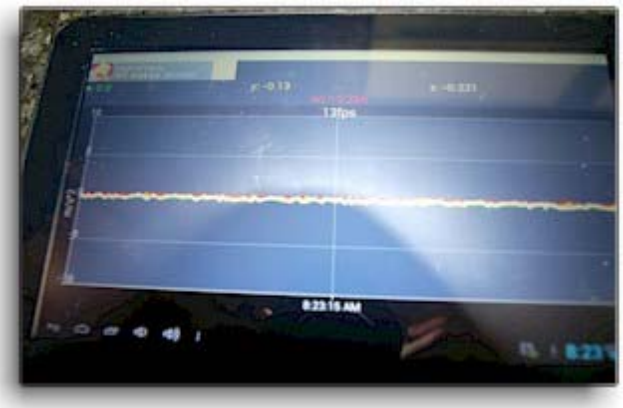
Should I Allow Vibration Monitoring?

You may well get a request to allow monitoring on your property, or the technician may simply come onto your property without permission, as was done routinely in the case with which I am most familiar. You should think through whether or not you wish to allow vibration monitoring on your property. Your best aid in making such a decision is to find out as much as you can about any previous monitoring done on the project, prior to the request to you. It is probably wise to **delay granting permission** until you have seen and analyzed any previously generated reports and data, with an eye to the possible mistakes that can be made in vibration monitoring (CVDG Pro). Since the vibration technician probably works for the contractor, you can expect that any errors made in seismograph setup, use procedure and data interpretation will not favor you. Whether problems exist or not, delaying a decision on allowing monitoring is about the only leverage you will have in getting the monitoring data, short of filing a lawsuit.

If you don't allow monitoring, you may not be able to stop monitoring in the public right-of-way portion of your yard (i.e. that part of your yard bordering the street reserved by ordinance for street or sidewalk expansions). If monitoring proceeds anywhere in your yard or immediately adjacent to it, **you are highly advised to videotape or photograph each and every installation of the seismograph**, noting the time of installation and removal, to the extent you are aware of them. Your record may well be the only reliable documentation of the way the work was done.

Do-It-Yourself Vibration Monitoring

Although it might be highly advisable to do your own vibration monitoring, as a check on monitoring done on behalf of contractors by vibration "professionals", that is beyond the financial capability of most homeowners. You can easily spend $10,000 or more to buy a monitor or hire someone to perform the monitoring. However, recently this picture has, at least in principle, changed dramatically.



Many modern cell phones and tablet computers have an entire suite of sensors, including acceleration sensors and a GPS location sensor, which can be accessed by software ("apps") to turn the phone or tablet into a do-it-yourself vibration monitor (see example at right, using a small, generic tablet). With small tablet computers available for as little as 30 USD and cell phones with similar capabilities just about everywhere, anyone experiencing construction vibration should seriously consider investing that much money to use the tablet or a phone as a mini vibration monitor. For more on how to use a phone or a tablet to do your own monitoring, see the CVDG Pro page, DIY Monitoring.

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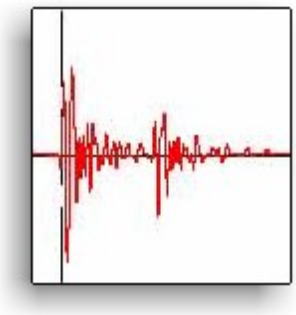
1. Blastmate III Operator's Manual, p. 1-1
2. USBM RI 8507, pp. 5-6
3. USBM RI 8507, p. 59
4. USBM RI 8507, p. 58
5. Federal Transit Administration's *Noise and Vibration Manual,* p. 12-11 - 12-12
6. *Google Earth* is an invaluable computer program, available for free download from http://www.google.com/earth. It provides satellite photos of almost the entire planet, at a resolution of a foot or so for most areas. You simply type in an address to find the most recent photo of that address. Historical imagery is also accessible from the program. Such photos are an excellent way to determine distances over the ground, using *Earth*'s Ruler feature.

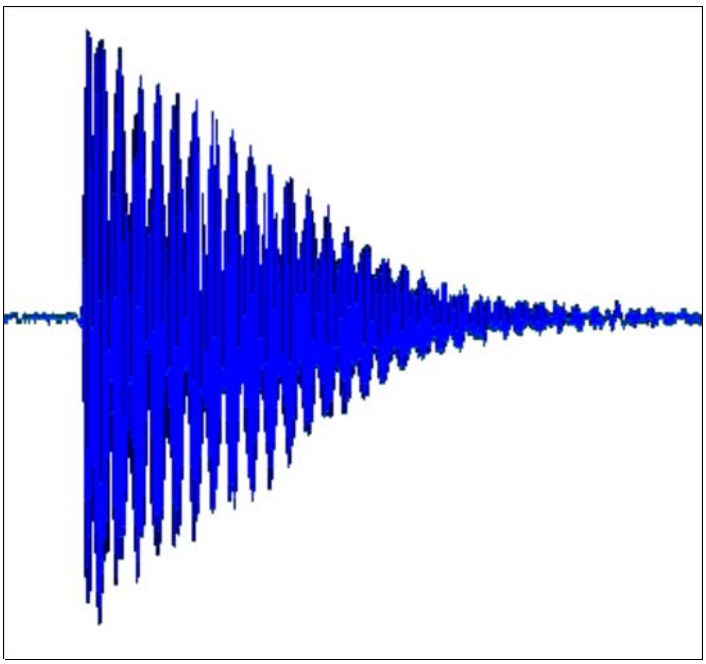
Vibration Frequencies



Real ground vibration wave traces from a seismograph, like the one at left, don't look anything like the simple sine and cosine waves discussed on the page, Vibration 101. They are much more complex. However, the complex ground vibration seismograph traces can be analyzed to reveal a complex sum of waves of different frequencies, intensities, and phase relationships (i.e. relative positions of wave peaks in the various components).

Vibration standards all over the world recognize that the potential for damage from vibration is strongly dependent on the frequencies present in the vibration. They set different "allowable" vibration intensities for different frequencies of vibration. Thus, finding out what wave frequencies and intensities contribute to the overall vibration is extremely important in gaining an understanding of its damage potential.

Waves and Frequencies



A plot of amplitude ("intensity" or "volume") vs. time for a single piano note sound (a vibration wave in air) is shown at right. The sound wave starts when the note is struck, oscillating rapidly and fading away over time, as shown in the graphic. A well-tuned piano or a tuning fork will have most of its volume at the main ("**fundamental**") frequency for the note. We could simply count the number of the largest "peaks" occurring in one second in this graphic to get a good approximation of the fundamental **frequency of the note, in cycles per second (Hertz, Hz)**.

However, there are some other little "squiggles" on the large peaks of the graphic which show that there are other, higher, frequencies present besides the fundamental frequency. These are called "overtones" and several of them occur at even multiples of the fundamental frequency. It quickly gets pretty dicey finding out much more than the fundamental frequency by simple inspection of such a graphic. Ground vibration amplitude vs. time plots are **much** more complicated than this single piano note. So, if we are going to be able to understand the makeup of even relatively simple ground vibrations, we need some help.

Zero Crossing Frequencies

One way of getting at some frequency information from a vibration is to use what is basically a measuring technique, much like that described above for the piano note. One simply looks at the largest peak in the vibration intensity vs. time plot like the one at the top of the page, measures its width in fractions of a second at the baseline of the waveform (i.e. between the adjacent points where the intensity is zero), then calculates 1 divided by this width (the "**inverse**" of the width) to calculate the number of such waves which one could "fit" in one second. This number approximates the frequency of the largest peak.

Seismograph software does this kind of calculation to give what is called a "**zero crossing frequency**" ("ZC frequency").[1] Indeed, the frequency numbers indicated on seismograph data reports are usually ZC frequencies, since they are available even when waveform data do not exist for a more complete analysis. The ZC frequency can be reasonably accurate for simple waveforms with sine-like shapes having few frequency components. It can be quite inaccurate for complex waveforms like those from ground vibration, especially when the largest peak is distorted in shape due to the overlap of multiple frequency components.

Fast Fourier Transform Frequencies

A far more accurate and informative method for determining **all** the frequency components of a complex wave is the use of **Fast Fourier Transform** (FFT). This is a mathematical technique, usually done with a minicomputer, in which the entire waveform of the ground vibration is "fitted" to a whole set of wave component frequencies, so as to obtain a full analysis of both the frequencies and their intensities which contribute to the vibration. FFT is extremely powerful and widely used. To learn more about how FFT is done and its many uses (e.g. medical MRI depends on FFT), but especially in ground vibration studies, see the *CVDG Pro* page, Fourier Transform. FFT can only be done when the full waveform is available. It cannot be applied to a vibration whose only record is a set of PPV's in histogram data.

Comparing ZC and FFT Frequencies

Some FFT-derived ground vibration dominant frequencies are compared with the corresponding zero crossing frequencies for the same events in the table at right. In each of these instances, the seismograph was located well within 50 feet of the vibration source. Thus, these reflect the source vibrations, not the formation of "low frequency wave trains" known to be prominent at larger distances, due mostly to soil absorption of the higher frequency components.

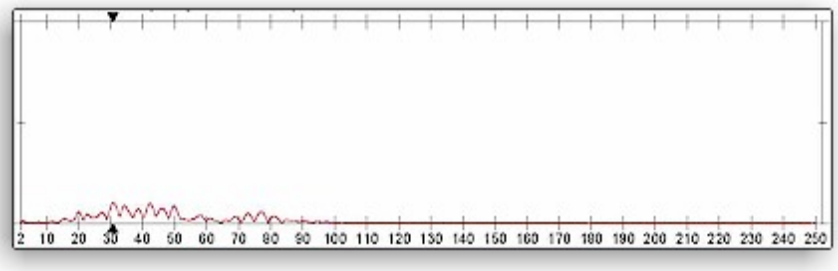
There are **always differences between the ZC and FFT frequencies**; some of the differences are quite large. For this reason, it is generally advised that one use FFT-derived frequencies in analyzing vibration data, not ZC

Activity	Event PPV (in/sec)	FFT Dominant Frequencies (Hz, t,v,l axes)	Zero Crossing. Frequencies (Hz, t,v,l axes)
"trenching and back fill"	0.180 0.140 0.08 0.0177	37, 37, 37 79, 76, 78 38, 38, 38 40, 40, 38	51, 47, 64 73, 73, 73 51, 64, 57 51, 64, 57
paving	0.320 0.330	58, 58, 40 40, 40, 58	64, 51, 57 43, 57, 51
final grade, paving bottom mat	0.165 0.340 0.180	46, 40, 45 52, 52, 52 69, 69, 69	43, 39, 47 57, 57, 51 64, 73, 73
milling cleanup, concrete	0.185 0.150	31, 27, 39 76, 33, 39	42, 23, 37 57, 43, 30

drop			
paving bottom mat	0.225	33, 34, 34	34, 39, 43

frequencies.[2] ZC frequencies should only be used where no waveform data exist to apply FFT, usually due to Memory Full Exits or "loss" of data. In that case, ZC frequencies should be considered as rough approximations to the real frequencies and given less weight in any analysis of damage potential.

FFT Vibration Spectra and Damage Potential



Unlike ZC crossing calculations, Fast Fourier Transform (FFT) analysis (*CVDG Pro*) of the vibration waveform provides the full vibration frequency distribution, not just an approximation of the dominant frequency. A full plot of the vibration frequency distribution vs. intensity, like the one at right, is called a "vibration spectrum" and is one of the most useful tools in determining the damage potential of a given vibration. Typically, vibrations generated by mechanical equipment (e.g. engine and other equipment with rotating or oscillating parts) have relatively narrow frequency distributions. Those generated by impact (e.g. pile driving or pounding on pavement with an excavator bucket) or impact-like activities (e.g. driving tracked equipment, pavement milling) have broad frequency distributions, like the impact vibration frequency (in Hz) plot at right. These "vibration signatures" are discussed in more detail on the *CVDG Pro* page, Vibration Signatures.

Vibration monitoring reports will often show only the Zero Crossing frequency of the the major vibration component and its velocity (PPV). This will then be used as the basis for a claim that the vibration "met the standard" or was "non-damaging". A comparison of the ZC and FFT frequencies for this vibration is shown in the "milling cleanup, concrete drop" entry in the table above. Setting aside the inaccuracies of Zero Crossing frequencies, such **single frequency-based conclusions have little meaning and virtually no import on the potential for damage** when the the vibration has a broad range of frequencies, as in impact-caused vibrations like that of the vibration spectrum just above. The dominant frequency there is about 42 Hz, with a low velocity of 0.185 in/sec. Thus, most vibration reports would indicate that this vibration would be "non-damaging".

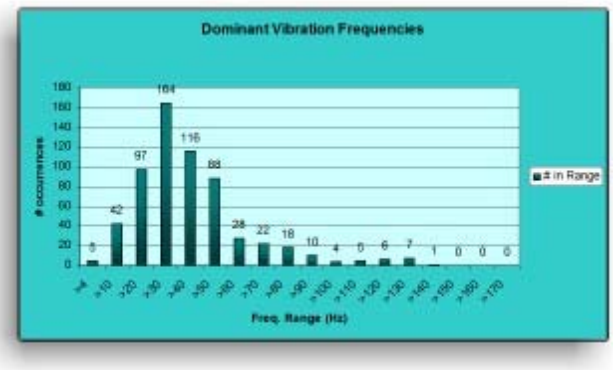
However, when we look at the whole spectrum, we find that there are multiple vibration frequencies below the 40 Hz criterion indicated in USBM RI 8507. Moreover, their intensities are very nearly the same as the 42 Hz peak. Many of them overlap home resonance frequencies. Even though the naive and incomplete single frequency analysis would claim this vibration to have been non-damaging, the fact of the matter is that this particular vibration is known from videotape records to have caused additional damage in a home already-damaged by the road construction operations which caused this vibration and the prior damage. Thus, **conclusions in vibration monitoring reports based on single zero crossing frequency analyses, especially when there are no available FFT-derived vibration spectra and no detailed information on the construction operations occurring at the time of the vibrations, should be viewed as poorly supported, at best.** They may well be literally invalid, as they were for this vibration.

This topic is discussed in much greater detail on the CVDG Pro page, Reporting Vibration Data.

Frequency and Damage Potential

As discussed in some detail on the page, Vibration Standards, most vibration standards recognize, and try to account for, the fact that vibration damage potential is frequency-dependent. Generally, frequencies below 40 Hz have the potential for most damage, because they can interact with the home's natural vibration frequencies in resonances to build higher and higher levels ("**amplification**") of home vibration. Unfortunately, the studies on which the vibration standards are based are almost entirely ones of blasting vibrations, where the short durations (typically, 2-3 seconds) of the blasting vibrations inherently limit the amount of resonant amplification which can occur to between factors of 2 and 4.[3]

The far longer vibrations from construction, which can last minutes, hours, days or even months, can enhance the additive effects of resonant interactions even more. Blasting vibrations have shorter durations than the vibrations in the homes which they produce.[3,4] This fact limits the degree of amplification which can be achieved. On the other hand, construction vibrations last longer than either blasting ground vibrations or ground-vibration caused home vibrations, so there is a greater opportunity for amplification in the house vibration. Unfortunately, there are few, if any, scientific studies which examine home resonance effects from long-lived construction vibrations.



While the dominant ground vibration frequencies vary in mine blasting, depending on the setting of the blasting,[5] construction vibrations generally have more intensity at lower frequencies than those from blasting (see road construction example diagram at right). What all this means from the standpoint of damage potential is that resonance effects, particularly the amplifications achieved, on house vibrations caused by construction are virtually unknown and poorly accounted for in existing standards.

1. Blastmate III Operator's Manual, page 5-9
2. USBM RI 8507, p. 59
3. USBM RI 8507, p. 44
4. USBM RI 8507, p. 30
5. USBM RI 8507, p. 6

Vibration Standards

Some understanding of ground vibration standards, how they were developed, what they say, how they are properly used and what their shortcomings might be in construction contexts is important to ascertaining the reliability of statements based on standards. Following is a relatively non-technical description of vibration standards generally, their important limitations, those most commonly used for construction and blasting vibration, how they may be properly applied and what their use might mean for someone whose home or property may have been damaged by construction vibration. *Vibration Standards* is one chapter of the over 100 page *Construction Vibration Damage Guide for Homeowners (CVDG)*, downloadable complete and free from Vibrationdamage.com or viewable online as web pages. Other pages of the CVDG expand on the subject of vibration monitoring, a discipline critical to the meaningful use of vibration standards.

Vibration Standard Criteria

The blasting seismograph vibration monitor (photo at left) translates its raw observations into a number of different measures of the speed of ground vibration. The one most accepted in the field is the **peak particle velocity (PPV)**[12]. This, as the name implies, is a measurement of maximum ground particle movement speed, specified in the U.S. in inches/second (in/sec). This quantity is measured in all three perpendicular axes of the seismograph's "**geophones**", as the magnet-in-coil detecting devices within the seismograph transducer head are called.

PPV is a **vector** quantity (i.e. it has both **a value** and an **associated direction**). The **peak vector sum** (PVS) is usually also quoted; it is simply the square root of the sum of the squares of the PPV values in all three vector directions measured by the seismograph. PVS is a **scalar** quantity, i.e. one with only a value, which is always larger than the individual PPV vector values. Scientific studies have shown **that the PPV correlates best with damage potential of all the tested characterizations of ground movement** (e.g. acceleration, displacement, or strain). Virtually all the standards are quoted in PPV values, not PVS or other measures of movement, although the acceptable values of PPV differ with the standard applied and with the frequency of the vibration components.

The three axes (directions) of measurement, the **longitudinal** (or "**radial**", the vector connecting the orientation arrow on the seismograph transducer and source of vibration),

transverse (the vector in the same plane as, but perpendicular to, the longitudinal) and **vertical** (up and down) vectors, are always measured and reported separately. One reason for this is that they have different degrees of importance in causing damage. Structures are built to withstand vertical forces. For that reason, vibrations along the vertical vector are usually of lesser importance in causing damage, though not always benign[11]. Vibrations in both the longitudinal and transverse vectors have the potential for causing **shear** in the home structure, which is a major contributor to damage effects. When in shear, various parts of the house move at different speeds or even in different directions, which can cause cosmetic cracking or even structural damage. Vibration standards generally do not take into account directly these differences in damage potential between vibration direction components, simply specifying the same limits for all three axes of measurement.

Understanding Vibration Standards

Vibration standards, like the OSM blasting standard and USBM RI 8507 blasting recommendations at right, are set forth by governmental agencies or professional groups to provide guidance to those who might be expected to cause vibration in their work and want to avoid causing damage. There are different ground vibration standards for different vibration environments and different building types (see below). Thus, a judicious and reasoned choice of which standard to apply in a given situation is critical to proper use and benefit of that standard.

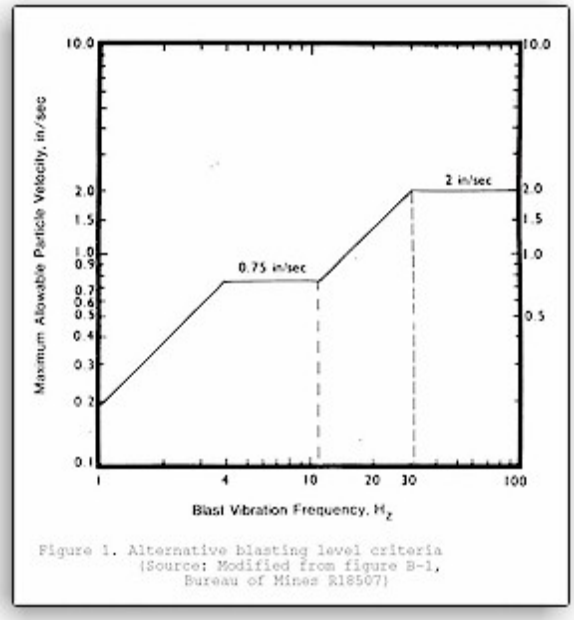


Figure 1. Alternative blasting level criteria (Source: Modified from figure B-1, Bureau of Mines RI8507)

OSM Blasting Standard

All scientific studies have limitations, including those of vibration damage and standards based on them. Within their scientific limitations, such standards can be invaluable in helping to avoid unnecessary damage by telling contractors and others when their efforts should be of concern. They also suggest when and how vibration can be reduced to avoid damage.

Vibration standards are usually plotted graphically similarly to the OSM standard and USBM RI 8507 study plots at right[6], using log (logarithmic or non-linear) scales in both the horizontal and vertical directions. The vibration intensity (velocity in inches/second) is on the vertical scale and the vibration frequency is on the horizontal scale. Vibrations deemed "allowable" in these standards fall below the central lines; "non-allowable" vibrations lie above the lines. Plotting the

standards linearly (i.e. with equal intervals between units on the scales) will change the shape of the dividing line separating "allowable" from "non-allowable" vibrations dramatically, but will not change the standard itself.

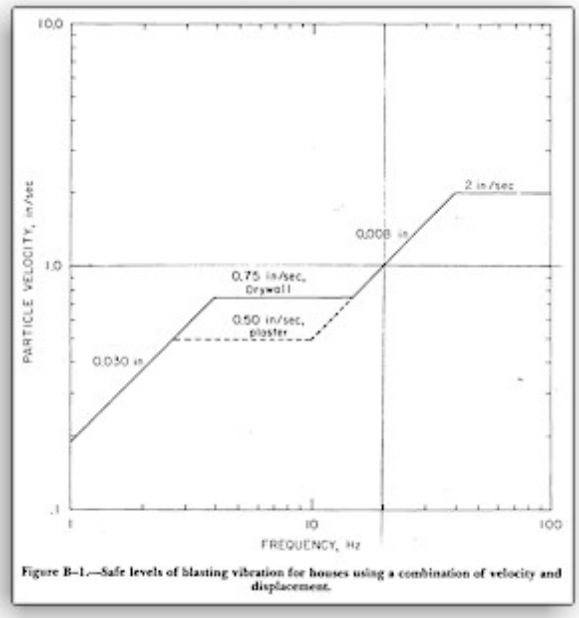


Figure B–1.—Safe levels of blasting vibration for houses using a combination of velocity and displacement.

USBM RI 8507 Safe Blasting Levels

Using Vibration Standards

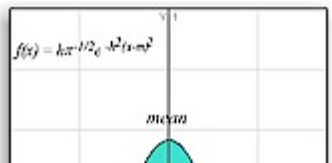
Because **not all vibrations felt by people are damaging to structures**, vibration standards attempt to separate those vibration intensities and frequencies which are potentially damaging to structures from those which may be concerning to people, but pose relatively little damage probability. It is important to understand that **standards are properly used to judge the probability of a single ground vibration of a given size, duration and frequency composition causing damage to a collection of houses or buildings of similar construction (see below), rather than the probability of multiple or long-lasting vibrations causing damage to one house or building.**[8] This differentiation is especially important in cases of construction vibration, where vibration is usually neither single nor short-lived.

One way of stating what the the OSM and USBM RI 8507 diagrams really mean scientifically is: "For a given **single blasting-caused vibration,** lasting less than a few seconds, with frequency components and intensities which fall below the dividing line defining the standard, 95% of essentially intact houses on firm foundations, two stories or less in height, having the dimensions of typical residences, will not be damaged by that vibration." That might be a mouthful, but that's what the standard and the data really say, at least within the confines of the USBM RI 8507 study which underlies both the standard plots above right. **If any of the assumptions or conditions which are behind a ground vibration standard are not met in a given situation, then any use of that standard in that situation is potentially both unwarranted and misleading**.

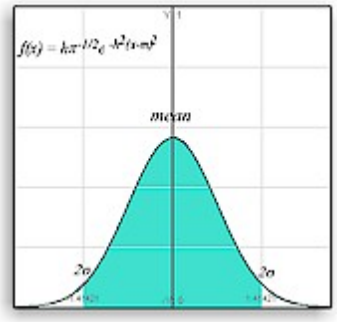
Standards and Statistics

For the blasting settings which have been, by far, the most extensively studied, it has long been recognized that **there is no given level of vibration which will or will not cause damage**:

> *"Two vibration limits are important; the level above which damage is likely to occur and the level above which neighbors are likely to complain. There is no precise level at which damage begins to occur. The damage level depends on the type, condition, and age of the structure, the type of ground on which the structure is built, and the frequency of the vibration, in hertz."*[10]



Acceptable vibration levels set in vibration standards are based



on statistical analyses of damage probabilities, assuming "Gaussian", bell-shaped data distributions like the one shown at left. **The statistical nature of standards means that not all vibrations which are deemed "allowable" (e.g. below the lines in the center of the standard compliance plots above[6]) in a given setting and standard will be non-damaging to all houses in all circumstances.** Similarly, not all vibrations deemed "non-allowable" (those above the central lines at right above) will **always** cause visible damage.

Thus, the mere fact that a given vibration is of an intensity within the "allowable" regime cannot be taken as **proof** that a vibration of an "allowable" PPV did not or will not cause damage. **It is scientifically inaccurate and misleading to say that it is "impossible" for a vibration of a given peak velocity (size) to cause damage to homes, even if it is within a given standard.** If damage occurs from a vibration known to be within the "allowable" regime of a standard, that fact does not imply, by itself, anything about the construction, condition or design of the house(s) damaged. It could reflect an expression of statistical variation, differences between vibration intensities measured at the site of the seismograph and those at the house, local soil or geology conditions, differences in the frequency composition of the vibration, or vibration conditions which violate the assumptions behind the standard (e.g. vibrations lasting longer than "a few seconds"), among several other alternative explanations.

Our *CVDG Pro* page, Statistics and Vibration Damage, provides more insight into the role of statistics in setting vibration standards and **the proper interpretation of the standards as reflective of probabilities, not certainties**. Such statistical limitations don't imply that standards are without meaning, but **they require that vibration standards be adopted, applied and interpreted thoughtfully and appropriately**.

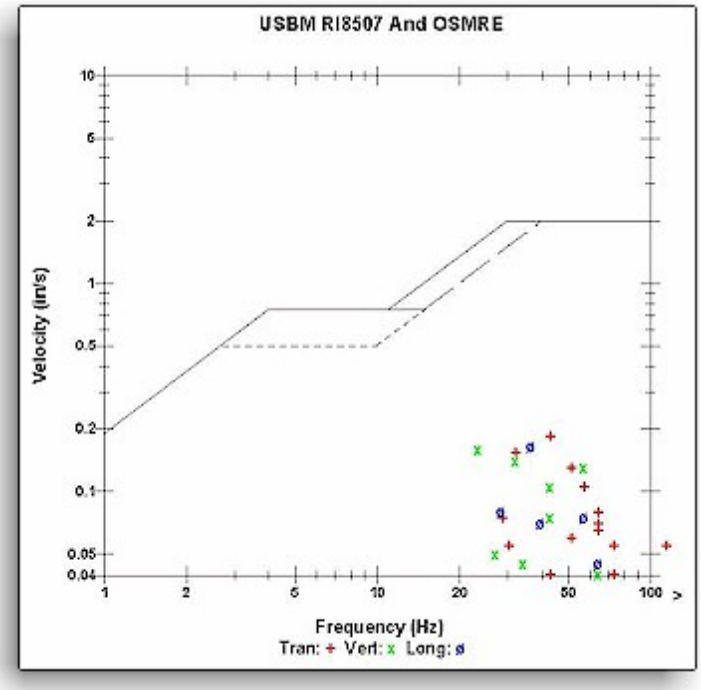
Frequency Dependent Damage Potential

As described on our page, Vibration 101, ground vibrations are usually complex, made up of multiple overlapping and interacting frequency components. The frequency components of the vibrations are important determinants of the damage potential. It is well known and understood that structures have natural vibration frequencies, called "**resonances**", a little like those of a tuning fork. Such resonant vibrations are more felt than heard, due to their low frequencies. At the home's resonant frequency, any repeated or long-lasting vibrations (more than a "few seconds"), like those caused by construction, can add to one another to produce even larger vibrations in the house structure (a process referred to as "**amplification**") than those occurring in the ground. The vibration in the house grows, rather than dying away in a few seconds. Thus, even small components of a vibration which occur at the resonant frequency are potentially dangerous to the home, if they continue sufficiently long. Such resonant phenomena also bring into play so-called "**fatigue**" (damage caused by repeated flexing) issues.

For this reason, most ground vibration standards take into account the frequency dependence of the vibration damage potential, setting more rigorous standards at lower frequencies nearer the home resonance frequencies than at higher ones. The OSM and RI 8507 blasting standards above both set lower ground velocity limits near home resonance frequencies than at higher frequencies, but these differences (a velocity factor

difference of 2.67 between frequencies above 40 Hz and at 10 Hz) are smaller than the observed amplifications (a factor of 4 for corner vibrations in homes, up to a factor of 8 for mid-wall vibrations), even for short-lived blasting vibrations.[9] This difference between the known amplification factors and the smaller velocity factors raises the question whether the velocity frequency factors may be set too low in those standards, even for blasting vibrations.

It is important to note that **vibration standards set limits for ground movement velocities, not for velocities of movement in the home**. Because of the self-reinforcing nature of vibrations with components at the resonant frequencies, home vibration velocities can be substantially higher than the ground vibration velocities. **Long duration, low frequency vibrations associated with construction are more worrisome than the relatively infrequent, short duration, higher frequency ones caused by blasting**. For more discussion of resonance and fatigue effects, see our page Resonance/Fatigue.



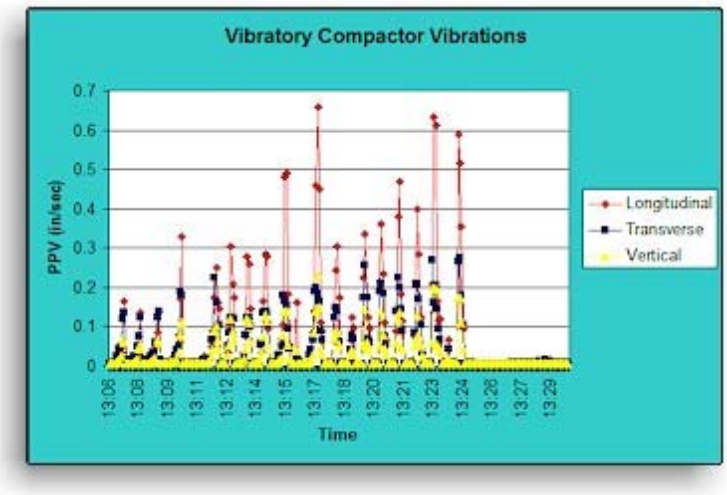
Blasting-Related Standards and Studies

By far the most commonly used **blasting** vibration standard in the U.S. is the U. S. Bureau of Mines, Office of Surface Mining (OSM) standard[1], shown above. It was developed in the early 1980's to address shortcomings of earlier, less stringent standards suggested by OSM. The **OSM standard** is based largely on a highly respected study done by the **U.S. Bureau of Mines, Report of Investigations 8507 (USBM RI 8507)** and studies referenced therein. As with most other standards, the OSM explicitly recognizes a frequency dependence of damage potential, with lower frequencies known to be more prone to causing damage. Many state and Federal agencies use this standard for blasting-related vibrations. An example of a construction vibration **compliance plot** showing the RI 8507 limits and the OSM standard is shown at right. It is worth noting that the vibration depicted there caused additional witnessed and videotaped damage, specifically correlated to a videotaped ongoing construction operation, in a home already damaged by construction, **even though all the points are well within the "allowable" regime under the line for this blasting standard**.

Differences Between USBM RI 8507 Safe Blasting Levels and the OSM Standard

In the frequency regime below 40 Hz, **two limits are defined in the USBM RI 8507 study, on which the OSM standard is based, one at 0.75 in/sec PPV for "Modern homes, Drywall interiors" and one at 0.5 in/sec PPV for "Older homes, plaster on wood lath**". The OSM standard does not explicitly recognize the Safe Blasting Levels of 0.5 in/sec PPV suggested in RI 8507 for "Older homes, plaster on wood lath construction for interior walls" at frequencies below 40 Hz[5]. Instead, it adopts the RI 8507 recommendation of

0.75 in/sec for "Modern homes, Drywall interior" at frequencies below 40 Hz. Thus, if you have plaster walls, the blasting recommendation in RI 8507 is lower than the OSM standard.



One further comment is in order regarding the USBM RI 8507 recommendations with respect to the 0.5 in/sec limit for houses with plastered walls. Many construction vibration types have these sub-40 Hz, higher intensity components. Often, they are the dominant frequency components (see Resonance/Fatigue). This differentiation is important, since vibratory compactor vibrations in a road construction job often exceeded the RI 8507 0.5 in/sec limit for plastered wall homes (see left for one of many examples), as well as several or all of the FTA standard limits (see below). Unless a detailed interior pre-construction survey is done to rule out the presence of homes with plastered walls in the relevant area, the 0.5 in/sec limit should be the one used, for only those parts of any construction jobs which involve blasting.

Misuse of Blasting Standards in Construction Settings

The OSM standard is based on studies of damage probabilities from single short-lived blasting vibration events, rather than the semi-continuous ones generated by road or other construction. **The USBM RI 8507 study, on which it is based, indicates that continuous vibrations might require a more stringent standard**:

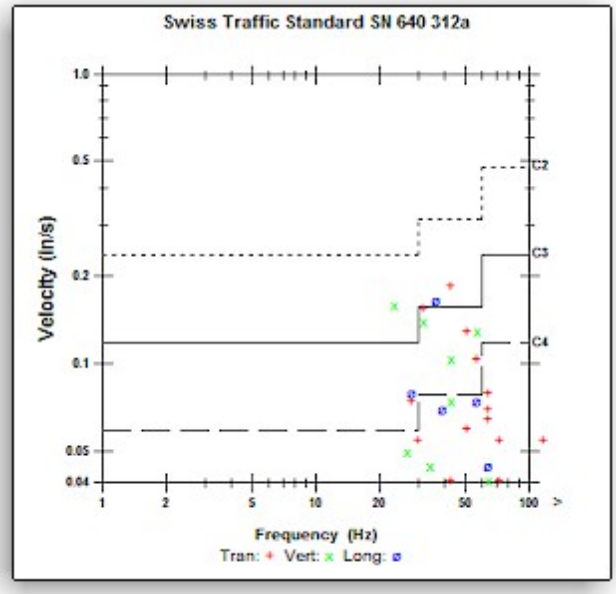
"The damage probabilities realistically refer to numbers of homes being affected by a given shot rather than the number of shots required to damage a single home....Additional work on fatigue and special soil and foundation types may later justify stricter criteria."[2] *(emphasis added)*

> *"Safe vibration levels for blasting are given in Table 13, being defined as levels unlikely to produce interior cracking or other damage in residences. Implicit in these values are assumptions that the structures are sited on a firm foundation, do not exceed 2 stories, and have the dimensions of typical residences, and that the vibration wavetrains are not longer than a few seconds."*[5] *(emphasis added)*

Despite these and other indications that blasting standards are inappropriate in settings with vibration lasting longer than a few seconds, the OSM standard is widely quoted, even outside of blasting. It is also **misused** by some governmental agencies and construction contractors for relatively long-lasting, non-blasting construction vibrations, probably because it sets relatively high limits on ground vibration intensities.

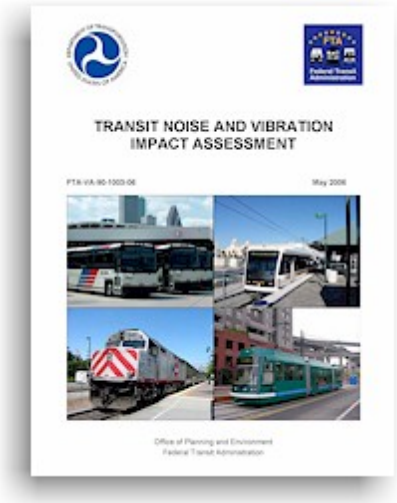
Because such differences in application are so important, one must make sure that the correct and most applicable standards are utilized in a given setting. Construction-based vibration standards must be used for construction and blasting-based vibration standards for blasting. **Use of inappropriate vibration standards is one of the most common mistakes made when vibration standards are cited**.

The Swiss Standards



Another set of ground vibration standards that is widely cited worldwide is the "**Swiss standards**" (SN 640 312a). There are actually three separate **"Swiss standards": one for blasting, a more rigorous one for pile driving and a still more rigorous one for machines and traffic**. The last of these is the one which is most applicable to road construction and use, as well as most other forms of construction. As with many other standards, acceptable levels of vibration in each of these standards are frequency dependent, with less vibration tolerated at frequencies below 60 Hz (Hertz, cycles per second) and still less below 30 Hz. The Swiss standards are not commonly used, *per se,* in the U.S., although they are widely cited and influential in ground vibration discussions and research. The Swiss SN 640 312a compliance plot at right shows the same vibration in the OSMRE/USBM RI 8507 plot above, caused by dropping a large chunk (about 1/2 ton) of concrete on the ground about 6 feet from the seismograph (from videotape of incident). It can be seen that the vibration at the seismograph is above several building type limits of the Swiss standard and of the related U. S. Federal Transit Administration standard, discussed just below.

Construction and Traffic Standards



The most relevant U.S. standard in a situation where the state or municipality has no, limited, or inapplicable construction vibration standards is the **Federal Transit Administration (FTA) standard**. The **Federal Transit Administration's** *Noise and Vibration Manual* (shown at left) is one of the most widely cited sources for vibration standards for road construction and traffic in the U.S. It is well worth reading in detail, as it has a great deal of summary information on vibration, noise and other construction impacts, beyond the vibration standard itself. It defines a standard for vibration in transportation-related construction situations, which is quite different from, and considerably more restrictive than, the OSM blasting standard. At the risk of some over-simplification, the FTA standard can be characterized as using the four structural categories and limits defined in the Swiss machines and traffic standard (quoted from Chapter 12 of the FTA standard[4, 13] below):

FTA Vibration Limits

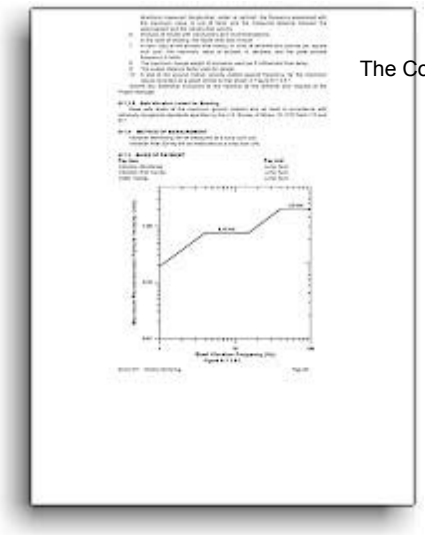
Building Category	***PPV (in/sec)***
I. Reinforced-concrete, steel or timber (no plaster)	*0.5*
II. Engineered concrete and masonry (no plaster)	*0.3*
III. Non-engineered timber and masonry buildings	*0.2*
IV. Buildings extremely susceptible to vibration damage	*0.12*

A typical modern, wood-framed home with drywall ("sheetrock", "gypsumboard") interiors and essentially no prior damage would be considered a Class III building. A home significantly damaged by construction or any historic home should probably be considered as a Class IV structure. While this assignment of damaged homes to Class IV might be disputed by some, my experience is that a road construction vibration of 0.185 in/sec PPV caused specific and traceable (i.e. videotaped) additional damage to a home previously damaged by construction. A comparison of these FTA vibration limits with the vibratory compactor vibration plot above shows that **the vibration levels from the compaction operation exceeded one or more of the FTA standards over 100 times in just an 18 minute period** in front of a single home. Most other homes in the area experienced many vibrations which exceeded the FTA standard. Over 600 vibrations in violation of the FTA standards were found in the partial data produced for the entire road reconstruction project.

The FTA standard differs slightly from the Swiss one in that it applies the high frequency PPV limit in the Swiss standard at all frequencies. Thus, this standard is **more lenient than the Swiss**, particularly at the lowest frequencies of most concern for resonant interactions with the home. However, it is far more confining on construction vibration than the OSM blasting standard. An expanded and updated version of the FTA Noise and Vibration Manual was issued in 2012 (shown at right). The 2006 standard is unchanged in that version. You can find links to download copies of most of these standards on our More Information page.

Municipal, State and Federal Vibration Standards

Individual state and Federal government agencies have set various standards for acceptable vibrations in various settings. They tend to be derived from, or identical to, one or more of the basic standards discussed here. Since Federal and some state highway departments have been among the most active in considering construction vibration issues, insofar as they impact road construction, one should survey his own state's DOT web site for information on construction vibration standards specific to road and other construction in that state, if any exist at all. In New Mexico, where I reside, the only road construction vibration



standard adopted by the New Mexico Department of Transportation (NMDOT) is the OSM blasting standard (see page at left)[3], **applicable only to blasting done during road construction**. **Other vibration-causing activities in road construction have no statewide standard in New Mexico, in spite of the potentially greater danger posed by them**. Since some state transportation departments in the U.S. have been among the most active entities involved in dealing with construction vibration, it is wise to check one's own state's DOT web site for information on vibration in road construction.

Many municipalities also have vibration standards of their own, which may not be identical to the state standards. You should check on the Internet for vibration standards in your city by using search strings like "[name of city] vibration". Unfortunately, such standards are too often set on the basis of advice from "experts" who do most of their work for construction or mining companies. Predictably, those standards are often based on the scientifically inappropriate, and much more lenient, blasting vibration standards, rather than construction standards. **One good way to know if a municipal or state construction vibration standard is based on the U.S. OSM standard for blasting is to look for quoted limits of 0.75 or 0.5 in/sec**. If these numbers are quoted, there is a high likelihood that the standard is derived from the OSM or USBM blasting standards. If your city has such municipal standards based on blasting, you should be prepared to challenge their appropriateness in a construction setting not involving blasting, should that become an issue.

Vibration Standards Worldwide

Most developed countries have human-caused (i.e. excepting earthquakes) ground vibration standards for at least some circumstances. Many of them are derived, in some ways, from the three discussed above. There are separate standards for Australia (2187.2), Brazil, Britain (British Standard 7385), France (Recommandation GFEE), India (DGMS A and B), the Czech Republic, Slovakia, Sweden, New Zealand (4403), Germany (DIN 4150) and Spain, just to name a few. In addition, there is an ISO (International Standards Organization) standard, ISO 4866 (shown at right in draft), an ANSI (American National Standards Institute) standard, ANSI S2.47-1990 (a U.S. counterpart of ISO 4866), and a draft ASTM (American Society for Testing and Materials) standard, ASTM WK7731. In the U.S., acceptable peak particle velocities are quoted in inches per second (in/sec), while most other worldwide standards are quoted in metric ("SI" ("Systeme Internationale"), "MKS" ("Meter Kilogram Second")) units of millimeters per second (mm/sec). Divide a standard quoted in mm/sec by 25.4 to convert it to in/sec.

Some of the standards referenced above do not set specific limits on vibration PPV's, but focus on proper procedures for measuring and analyzing vibration data. Others of these worldwide standards deal with machinery vibrations in factory settings, as well as

construction and blasting-caused ground vibration. Most compare human vibration perception with the, often different, vibration levels necessary to cause damage in structures. There are also some different, far more stringent, vibration standards for areas which house some types of sensitive scientific or medical equipment (e.g. laser tables, MRI machines, spectrometers of various types, electron microscopes, etc.).

Of the world vibration standards, the FTA, Swiss, OSM, German, British and ISO standards seem to be the most cited within the ground vibration literature. You can get PDF-format electronic copies of virtually all of them over the Internet, though you may have to pay for some of them.

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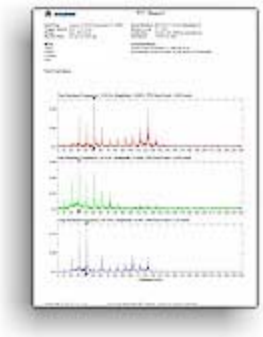
1. OSMRE Blasting Guidance Manual, p. 24
2. USBM RI 8507, p. 59
3. NMDOT Standard Specifications for Highway and Bridge Construction, Section 617, pp. 433-434.
4. Federal Transit Administration's *Noise and Vibration Manual,* p. 12-13
5. USBM RI 8507, p. 58
6. OSM Blasting Performance Standards, 30 Code of Federal Regulations, Sec. 816.61, page 7
7. USBM RI 8507, p. 77
8. *"The damage probabilities realistically refer to numbers of homes being affected by a given shot rather than the number of shots required to damage a single home."* USBM RI 8507, p. 59
9. USBM RI 8507, p. 33, *et seq*.
10. USBM IC 8925, p. 79, *et seq*.
11. USBM RI 8507, p. 38
12. "*From this analysis the conclusion is drawn that a given degree of damage to a structure is most closely related to the magnitude of the particle velocity of the wave motion passing thru the earth at the structure location*." USBM RI 5968, p. 1
13. An expanded and updated version of the FTA Noise and Vibration Manual is: *High-Speed Ground Transportation Noise and Vibration Impact Assessment*, Carl E. Hanson, P.E., Jason C. Ross, P.E., and David A. Towers, P.E., DOT/FRA/ORD-12/15, September 2012

Resonance/Fatigue



Typical construction vibrations are usually composed of many frequency components, which, when added together, create the vibration seen. The specific makeup of the vibration components is a critical determinant of the vibration damage potential. It is well-known and understood that structures have natural vibration frequencies, called "resonances", a little like those of a tuning fork or a bell. **At the home's resonant frequency, any repeated or continuous vibrations, like some of those caused by construction, can augment ("amplify") one another.** This causes the vibration in the house to grow, rather than dying away due to the natural damping in the house structure. Thus, even small components of a vibration which occur repeatedly or continuously at the resonant frequency are potentially dangerous to the home.

A Simple Analogy

As an example illustrative of how resonance works, imagine that you are pushing someone on a swing. If you time your pushes to coincide exactly with beginning of the forward movement of the swing, the person in the swing will go higher and higher. That's because you have timed your pushes to be in **resonance** (in physics terms, "**in phase**") with the period of the pendulum motion of the swing. The growth in the swing's motion with repeated resonant pushes is an example of **amplification**, discussed below in the context of home vibrations. If your timing is a little less than perfect, you may still contribute to the swing's motion, but far less efficiently than if you had timed it perfectly. These less-than-perfectly-timed pushes are said to be **"non-resonant"**. If you stop pushing, the swing's momentum will slowly die out, due to friction and air resistance. Those are forms of **damping** (discussed below in the context of home structures).

Suppose now that, instead of pushing just at the right moment, you push both then and at a time when the swing is at the top of its arc. On every second push, you will provide forward momentum to the swing, but the push at the top of the arc will be wasted (in physics terms, "**out of phase**"). That example shows why pushes at even multiples of the "**resonance frequency**" of the swing will still contribute to its motion, though progressively less effectively as the frequency of the pushes increases. These even multiple, higher frequency pushes are called "**overtones**" in physics; they contribute to the swing motion, even though they are not directly in resonance.

Additive Vibrations in Homes

Going back now to vibrations in homes, it's easy to see that vibration frequencies whose wave peak intensities or "**amplitudes**" ("pushes") are equal to or are at even multiples of the home resonance frequency will cause vibrations in the home much more efficiently than those frequencies which do not meet these conditions. Each passing ground

vibration wave peak in resonance with the home's natural vibration frequency and matching a peak in the house vibration causes an increase in the vibration in the home. Since a given vibration can have many additive peaks in the minute or more that a typical construction vibration lasts, such vibrations are of considerably more concern than those which last only a few seconds. For a 20 Hz vibration frequency, there are 20 peaks per second times 60 seconds = 1200 such peaks in one minute, each of which can reinforce the vibration in the house structure. The reinforcement and growth of resonant vibrations makes these particular vibrations unusually dangerous for the structure. **The longer the vibration lasts, the worse the situation gets. For long lasting vibrations, even small resonant components below any vibration standard can become dangerous for the home.**

In-sync and Out-of-sync Vibrations

Even if the incoming ground vibration waves and the house vibrations are completely unsynchronized ("out of phase" or "out-of-sync"), such that incoming wave peaks coincide exactly with wave troughs in the house vibration movement, resonance still makes itself felt. To see how this works, consider the case where we have complete out of phase interaction, i.e. where the incoming ground vibration wave peaks exactly match the house vibration troughs and have the same intensities. This will result in a complete loss of the house vibration at that frequency, due to interference effects, in one cycle of the ground vibration wave. However, the very next incoming wave peak will start the house moving again, but this time, in synchronization ("in phase") with the incoming wave train. Subsequent wave peaks will now all be in sync with the house motion and will add their energy to it.

In effect, interference between the house movement and the ground movement quickly "pulls" the house movement into phase sync with the resonant ground vibration. If the house resonant frequency is at 10 Hz (i.e. 10 passing wave peaks per second), this means that, within 0.2 second, the house vibration and the 10 Hz component of the ground vibration will come into sync. A little thought will show that, even if the ground vibration wave peaks do not coincide exactly with the house vibration troughs, interference will eventually bring the house and ground movements into phase by canceling out-of-phase components and reinforcing in-phase components. It may take one or two seconds, but it will happen quickly relative to the time scale of typical construction vibrations. So, **resonant effects are always felt if the vibration frequencies match those of the house, irrespective of the initial phase relationship of the incoming ground vibration and the house vibration.**

Resonance Effects and Damage Potential

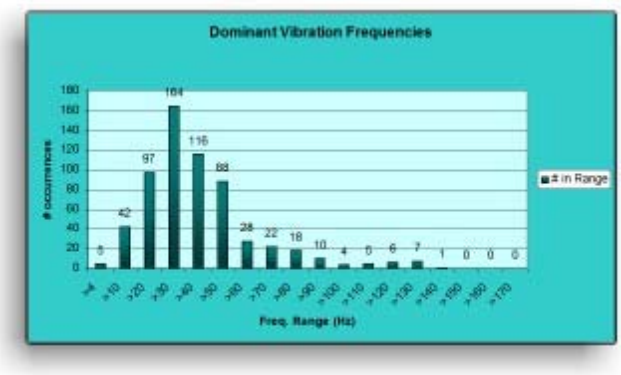
Actual home resonance frequencies can be easily determined by attaching a seismograph to the house wall, vibrating the house, then turning off the vibration. The house will continue to vibrate for a few seconds at its resonant frequencies. For whole home vibrations, the **resonance frequency is in the range of 8-12 Hz**, typically. For vibrations of individual walls, that frequency is around 20-25 Hz (see USBM RI 8507[1]). **Such vibration frequencies are more felt than heard**. Structure resonant frequencies can also be calculated from engineering principles, but the results are often inaccurate in the simplest such calculations.

The growth of vibrations in a house due to resonance is referred to as "**amplification**". Amplification in houses has been measured and reported in USBM RI 8507[2] and for a greater range of structural types in reference 6). For mid-wall vibrations (i.e. those responsible for pictures rattling, for example), the **amplification can be as high as a factor of eight in blasting** vibrations. For corner vibrations (those responsible for cracking at wall penetration corners), it can be **as high as a factor of four in short-lived blasting vibrations**. It is highly likely that long-lasting construction vibrations could produce even higher amplification factors. Note that, even though we have discussed mid-wall and whole house vibrations as separate entities, the **mid-wall vibrations can transfer their energy to whole house vibrations**. Thus, ground vibration frequency components in resonance with the mid-wall vibrations can still excite the lower frequency (and, hence, lower energy) whole house vibrations. These phenomena are discussed in more detail on the CVDG Pro page, Vibration and Homes.

Due to these resonance phenomena, most ground vibration standards take into account the frequency dependence of the vibration damage potential, setting **more rigorous standards at lower frequencies** than at higher ones. Because of the self-reinforcing nature of vibrations with components at the resonant frequency, **continuous vibrations associated with construction are considerably more worrisome than the occasional short duration ones caused by surface mine blasting**. For example, USBM RI 8507[3] has this quote:

> *"The safest approach is to consider the low-frequency part of the time history separately, and where it is below 40 Hz, use the 0.75 in/sec or 0.50 in/sec criteria. If Fourier spectral analysis is used, any spectral peak occurring below 40 Hz and within 6 dB (half amplitude) of the peak at the predominant frequency justifies the use of the lower criteria."* (emphasis added)

Construction Vibration Frequencies



At left is a chart display of just the **dominant frequencies** of vibrations in a road construction job, extracted by FFT analysis (CVDG Pro) of the waveform vibration data. These data reflect most kinds of road construction activities, though they do not include the majority of the most intense vibrations (due to early seismograph Memory Full Exits), nor the tracked excavator pavement pounding that was most damaging. Directly contradictory to sworn statements made by the construction company and their "experts" - that the predominant vibration frequencies from the construction were over 60 Hz in frequency - you can see from the diagram that a large majority of the vibrations for which waveform data were obtained had **dominant** frequencies below the 40 Hz cutoff mentioned in the RI 8507 quotation above.

Not only was **the predominant frequency of most vibrations in a road reconstruction construction project below this 40 Hz frequency criterion**; those peaks meeting the half-amplitude criterion of USBM RI 8507 were an even larger fraction of the vibrations.

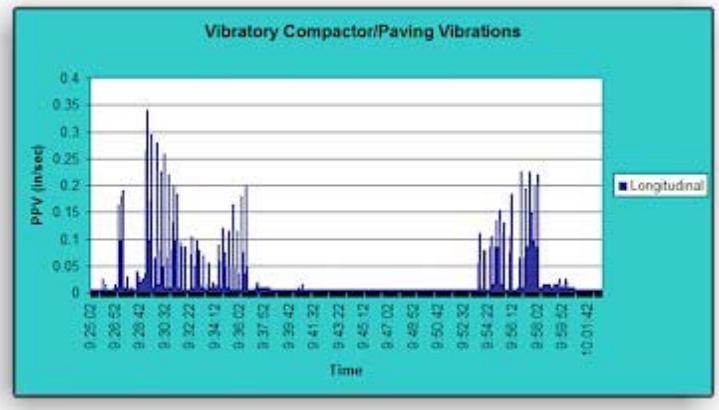
This is a good example of why one must look carefully at vibration monitoring data to make sure they are being properly presented and interpreted.

Non-resonant Vibrations

Resonant vibrations and frequencies are of most concern in causing damage, simply because they are most efficient at exciting vibrations in the house. However, **vibrations at other frequencies are not entirely benign**. The reason for this caution is that, no matter what the frequency of the exciting vibration, some portion of the energy of the non-resonant vibration ultimately is "**partitioned**" (i.e. distributed) into the home resonant frequencies, which persist for several seconds after the vibration stops. This is the reason that one can determine the home resonance frequencies by vibrating the house, then monitoring the vibrations in the home after the exciting vibration ceases. Non-resonant vibrations don't have the self-reinforcing character of resonant ones, but, if they continue for a long time or they are large enough, they can cause damage by their partitioning into the resonant frequencies of the house. This topic is developed more fully in the CVDG Pro page, Vibrations and Homes.

Construction vs. Blasting Vibration Exposure

Below are some tabulated total **displacements,** D_t, (accumulated movement in inches), one measure of total vibration exposure, determined by me from actual vibration data in a road reconstruction job. The displacements are obtained by calculating in a spreadsheet program the areas under the PPV vs. time curves (see example at right) for ASCII-exported histogram vibration data.[8] Details of the calculations and interpretation of these data are found in the CVDG Pro page, Vibration Exposures.



Activity	Approx. Duration	Max PPV (in/sec)	Approx. Seis. Distance	D_t (t) (in.)	D_t (v) (in.)	D_t (l) (in.)	Est. Blasting D_t
Asphalt Paving/Compaction, 1st mat, 1st lane	15 min.	0.34	7 ft.	19.45	16.55	33.825	1.5
Asphalt Paving/Compaction, 1st mat, 2nd lane	7 min	0.23	20 ft.	8.925	8.55	17.95	1.5
Asphalt Paving/Compaction, 1st mat, 1st lane	2 hr.	0.33	5 ft.	51.575	33.45	22.525	1.5
Excavator Drive-by	1 min.	0.085	20 ft.	1.75	1.75	1.6	1.5
Pavement Milling	2.25 hr.	0.165	5 ft.	56.125	46.025	33.575	1.5
Excavation	8 hr.	0.170	35 ft.	133.1	56.675	58.025	1.5
Pavement Removal	6.5 hr.	0.150	70 ft.	34.675	9.225	22.975	1.5

Activities are derived from videotape records. Seismograph distances are for the closest approach point to an in-calibration seismograph. They were obtained from video records of location of work and placement of seismograph, using Google Earth to determine distances from the locations. Estimated distance error is ±10%. Seismographic information comes from original raw data, exported to ASCII and analyzed in Excel. Data for all three measurement vectors are included. Blasting displacements are derived from a "worst case" allowable 2.0 in/sec PPV, with durations estimated from data in USBM RI 8507[7]. Max PPV's are for a single zero crossing frequency, not the entire frequency distribution, since very few cases had complete waveform data for the day or operation.

The main reason for the small total displacement in blasting is the short duration of the vibrations. **Construction vibrations cause so much more displacement because they last far longer and are repeated far more times**. The first two entries in the table above are for two different passes of paving over soil on the same day. When we add the results together, we can see that houses on that street experienced in a little over 20 minutes of one day vibration displacements that would take over a month of once daily, worst-case blasting to bring about.

The data above are only a sample of data from a job that lasted 5 months at the location where the data were recorded. As has been discussed several times in the CVDG, most of the likely highest (and longest) readings were "lost" by the vibration technician, his company, and the contractor. Other data are unusable due to the the employment of an out-of-calibration seismograph in the measurements. Those data have also been excluded from the tabulation above, although the highest PPV's were measured with that seismograph. The total amount of time reported above is equivalent to less than two days of work in that 5 month-long job. While not all days produced vibration with large PPV's, nor is a large maximum PPV necessary to produce large displacements, it is easy to see that the **total vibration exposure in construction jobs for single days is tens to over a hundred times higher than "worst case" blasting near an active surface mine over the same period**.[8]

There are few cases, if any, in the vibration literature of comparisons of amounts of vibration **exposure** from construction operations vs. those from blasting. Although peak particle velocity (PPV) is the basic criterion used in vibration standards to estimate damage potential, displacement has been advocated as a more appropriate measure of damage.[9] While it is known that fatigue effects in blasting are dependent on vibration exposure (see just below)[4], establishing a quantitative relationship between damage and vibration exposure in construction must await further research. In particular, the displacement might be expected to be most relevant to possible damage in cases where the vibrations have significant components at the self-reinforcing resonant frequencies of homes, as in construction vibration generally (see above). **Total displacement calculations demonstrate both a need for far greater concern about construction vibrations and the limitations of blasting standards in construction environments**.

Fatigue Effects

Most of us are familiar with the experience of breaking a paper clip or a piece of hard plastic. If we bend it once, nothing much happens beyond the bending. If we continue to bend back and forth in the same spot, eventually the paper clip will break. This is an example of material **fatigue** in the technical sense. Different materials experience fatigue for different reasons, depending on their innate molecular structures and properties. For example, in bendable metals, the primary fatigue process is the movement and accumulation of **dislocations** (faults in location or filling of atomic positions) in the metal crystal structure.

Houses can also experience fatigue if they are vibrated many times or, worse yet, continuously. In blasting settings, it can take many blasts for the house to develop fatigue cracking. However, because construction vibrations are often continuous for minutes, hours, days or even months at a time, they can give the house an accumulation of vibrations that would take many thousands of blasts to achieve in blasting at a mine or

quarry site (see failure strain and fatigue effect diagram from USBM RI 8507[4] at right), as calculated quantitatively above.

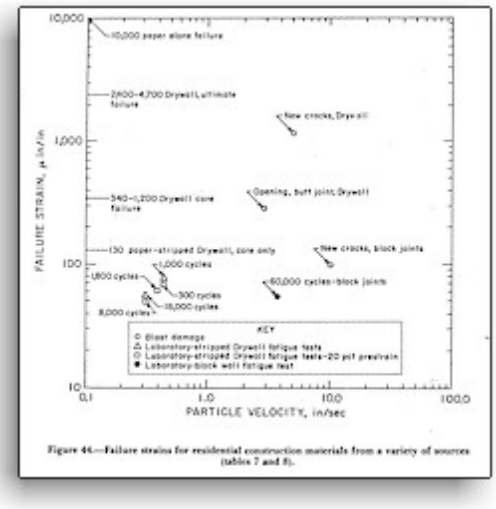


Figure 44.—Failure strains for residential construction materials from a variety of sources (tables 7 and 8).

Fatigue effects in construction vibration are an area of current research, since they are not fully understood for construction settings. However, most scientists acknowledge that fatigue is more likely to manifest itself with construction vibrations than with blasting vibrations. The total displacement calculations discussed above provide strong evidence for that expectation. There is more discussion of fatigue effects and their role in construction vibration on the CVDG Pro page, Vibration and Homes. In short, while excellent blasting vibration studies like USBM RI 8507 have real value, **blasting standards, by themselves, are likely to be poor predictors of damage potential in continuous or extended vibration settings, like those in construction**.

Damping

While resonance tends to reinforce and prolong structure vibrations, its opposite is **damping**, whose effect is to cause vibrations ultimately to die away. Damping values for homes have been measured and reported in USBM RI 8507[5]. They are typically in the range of **2 to 4% of "critical damping"** (i.e. that level of damping which causes instantaneous loss of the vibration). The low damping value for homes means that vibrations can persist for long enough that **resonance reinforcement by continuous vibrations can easily occur**.

This discussion of resonance, amplification, fatigue and damping is, by no means, exhaustive of all the matters that should be considered in evaluating resonance effects and their role in causing damage. I hope that it will help homeowners better understand the terms and their importance, so they can read the literature more productively and place claims about damage potential based on blasting studies in proper scientific context.

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1. USBM RI 8507, pp. 30-31
2. USBM RI 8507, p. 33, *et seq.*
3. USBM RI 8507, p. 59
4. USBM RI 8507, p. 44
5. USBM RI 8507, pp. 30-31
6. *COMPARATIVE STUDY OF STRUCTURE RESPONSE TO COAL MINE BLASTING,* Prepared for Office of Surface Mining Reclamation and Enforcement Appalachian Regional Coordinating Center, C. T. Aimone-Martin, M. A. Martell, L. M. McKenna, D. E. Siskind, C. H. Dowding
7. USBM RI 8507, p. 30
8. The equation by which these total displacements can be calculated from ASCII exports of histogram data is:

$$D_t = t_i*(\Sigma(PPV_{axis})-b_c*n_p)$$

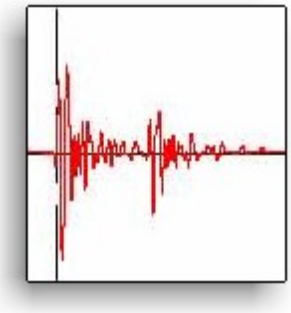
where: D_t = total displacement

t_i = seismograph data interval in seconds
PPV_{axis} = individual PPV's for each recording axis separately
b_c = lowest PPV level recorded for background
n_p = number of data points in summed range
Σ = Greek capital letter sigma, denoting a summation of the PPV's for each axis

The CVDG Pro page, Vibration Exposure, has details on the calculation, including use of frequency weightings, equation applications and discussion of its limitations. It also includes a paste-in Excel formula for doing this analysis for other exported histogram data.

9. C. H. Dowding, *Measure the Crack Instead of Construction Vibrations*, http://www.iti.northwestern.edu/acm/articles/geostrata.html

DIY Vibration Monitoring



Do-It-Yourself Vibration Monitoring

Although it might be highly advisable to do your own vibration monitoring, as a check on monitoring done on behalf of contractors by vibration "professionals", that is beyond the financial capability of most homeowners. You can easily spend $10,000 or more to buy a monitor or hire someone to perform the monitoring. However, recently this picture has changed dramatically, at least in principle.

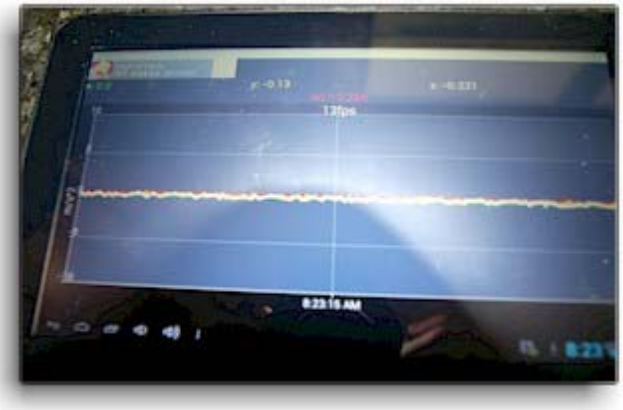
Many modern cell phones and tablet computers have an entire suite of solid-state sensors, including 3-axis acceleration sensors and a GPS location sensor, which can be accessed by software ("apps") to turn the phone or tablet into a do-it-yourself vibration monitor. Most Apple-manufactured iOS-based devices, have these sensors, as do many tablets and phones based on the Android® operating system. Microsoft® devices also have such sensors. Generally speaking, if your phone or tablet will switch between landscape (as seen in the photo below) and portrait display modes automatically as you change its orientation, it probably has at least acceleration sensors. It may have a number of others. A list of some of the commonly implemented sensors in mobile devices is just below. All devices may not have all of these, but almost all made since 2009 or so will have 3-axis accelerometers.

Sensor Type	Purpose
Accelerometer	*Motion detection (shake, tilt, etc.).*
Ambient Temperature	*Monitoring air temperatures.*
Gravity	*Motion detection (shake, tilt, etc.).*
Gyroscope	*Rotation detection (spin, turn, etc.).*
Light	*Controlling screen brightness.*
Linear Acceleration	*Monitoring acceleration along a single axis.*
Magnetic Field	*Compass directions*
Orientation	*Determining device position.*
Pressure	*Monitoring air pressure changes.*
Proximity	*Phone position during a call.*
Relative Humidity	*Monitoring dewpoint, absolute, and relative humidity.*
Rotation Vector	*Motion detection and rotation detection.*
GPS	*Global Positioning System location*
Temperature	*Monitoring temperatures.*

To the extent that a given device has each of these sensors, they can be accessed directly by programming. This capability is the basis for apps which use the sensors.

Reading the Accelerometers

There are free apps for each type of device operating system which will tell you what sensors you have in your device and monitor one or more of them for you at a time. You can get these apps at numerous online app stores, e.g. the Apple Store (for iOS®) and Google Play (for Android®), among many others. To find them, just search for "sensor apps [name of operating system or device]".



A number of iOS® and Android® apps will use the built-in acceleration sensors to turn your phone or tablet into a simple vibration monitor. The apps are usually free; a few charge a nominal fee for what is usually a more capable app. You can find these by searching for "vibration monitor apps [name of operating system or device]". An example of one such free app running on a small, generic tablet is shown at right. Three overlapping curves are visible in this trace, since this app monitors all three axes. Some apps perform full FFT vibration analysis of the vibrations (see CVDG Pro for information on FFT). Typically, they will store the data to a file which you can download for analysis on a larger computer, print or view later. Since virtually all tablet computers and most cell phones have Internet access, you can send results to yourself that way, without need for a sync cable.

Using DIY Acceleration Data

These apps and devices are not yet fully developed for serious scientific vibration monitoring at this point in time. They often have adequate hardware capabilities, but are still somewhat limited in software capabilities after you acquire the data. To some degree, these limitations are imposed by the device speed and memory, but those limitations should become less important as the technology develops.

Mobile device sensors inherently monitor acceleration, not the ground movement velocity that seismographs measure. The acceleration data can be converted to velocity by numerical **integration** (i.e. determining the area under the intervals of the acceleration vs. time curve generated by the accelerometers). This is most readily done by importing the acceleration data into a spreadsheet, then determining the areas under segments of the acceleration curve by using a "trapezoidal approximation" for the point-to-point integration. For more information on converting between the various measures of vibration, see the CVDG PDF version page, Vibration Measures (not available online).

Small tablet computers are available for as little as $30 in the US, and prices are dropping continuously. 16 GB SD cards, more than sufficient for recording the all the data from a project lasting several months, run less than $8 in the US. Anyone experiencing construction vibration should seriously consider investing that small amount of money to use the tablet or an extra smartphone as a mini vibration monitor.

Installing Your DIY Device

Before you attempt DIY vibration monitoring with a cell phone or tablet computer, read

the *ISEE Field Practice Guidelines for Blasting Seismographs*, (see the CVDG More Information page for a link to download it). This will help you set up your phone or tablet in a manner that will allow you to get the best data available from your device. Here are a few tips for installing your device in a manner that will make the data more reliable and defensible, based mostly on the ISEE recommendations for blasting seismographs:

- **Consider installing two or more such devices**, anchoring one to a corner of your home closest to the construction, another in the middle of the wall closest to the construction, and, perhaps, a third near the base of your foundation closest to the construction.
- If your installation is outside, **wrap the device tightly in a plastic bag to keep it dry and clean**.
- **Make sure that the device is securely mounted**, so that it moves as does the wall or ground. Outside, this can be accomplished by placing a zip-type plastic bag filled with sand over your device. This is usually more than sufficient to anchor the device against all but the largest accelerations. **Use removable fasteners to secure it tightly to interior walls**, thereby avoiding the need for damaging the wall to mount the device.
- **Make sure the device is calibrated**. Virtually all the apps that do vibration monitoring provide at least some capability to do this. More on calibration follows this list.
- Battery life is long enough in most tablets and smartphones that they can record a full day's data. If that isn't the case with your device, **make provision to keep it charged when in use**. Charge it again during non-working hours.
- **Provide adequate memory to record the data**. This is most readily accomplished by adding a micro-SD or other memory card of the sort accommodated by your device. This card should have at least 4 GB capacity, with the more, the better.
- **Set up your vibration monitoring app to record the data to a file on the SD card**. Make sure that the app doesn't overwrite previously acquired data by checking the app configuration before you start. It's wise to download the file containing the data every night.
- If possible, **set up the app to subtract the acceleration from gravity (see above photo)**. The acceleration due to earth's gravity is about 9800 mm/sec^2 (slight differences from locale to locale), compared to human-caused vibrations between 0 and 200 mm/sec^2, or so. The vertical axis sensor will reflect this, making vertical axis construction vibrations hard to see.
- **Document your device installation with photos** showing the device in place.
- **Carefully and consistently choose and note the orientation of the device with respect to the construction**. Conventionally, the longitudinal direction, as indicated by an arrow on the seismograph head, is oriented toward the location of the work or point of closest approach. Since electronic devices don't have such arrows, orient the long dimension of the device toward the work, where your installation allows. Interior wall locations may not allow this. In that case, orient the long dimension consistently along the longest dimension of the wall. Note these details in your log.
- **Keep a log of information regarding the installation**. This should include the exact location, the orientation, the type of construction activities which were occurring during its period of operation and the distance to the activities or their point of closest approach. The log need not be long and can be done either in a word

processor or spreadsheet program right on the device itself or on a separate computer.

- **Record the exact position of the device with respect to fixed landmarks or structures**. If your phone or tablet has a GPS sensor, this information can be gotten from it.

"Calibration" (establishing that your accelerometers read correctly against known standards) is critical to obtaining **quantitative** data from your sensors. Many of the apps have simple calibration procedures built into them. If so, you should follow them. Another way to know if your sensors are reading correctly from a quantitative standpoint is to check the value reported for the vertical (or "z" axis), before any offset applied by the software. In a vibration-free environment on a level surface, the vertical axis should read at or very near to one standard earth gravity, "*g*" (9.8 m/sec^2 or 386 in/sec^2). The other two axes should read very near zero in a level, vibration-free environment. If your readings are something else, the apps usually allow you to correct the number.

The photo above shows a monitoring app which has been calibrated in the vertical axis and has had the gravitational acceleration on the vertical axis subtracted. The movement seen is essentially "noise". By showing that you have calibrated the vertical axis against a well-known value and established that the other two axes read near zero when vibration-free, you can show reason for confidence in your quantitative data. If you follow the tips indicated above, you may well find yourself in a position to call into question the work of some vibration monitoring "professionals", at least some of whom are **far** less careful.

DIY Vibration Data and Litigation

Accelerometer-equipped cell phones and tablets can provide some very valuable assistance in verifying vibrations as you videotape construction operations or for doing some non-destructive monitoring inside your home. They are far superior to using water in a bottle as a **qualitative** (i.e. existence of vibration, as at right) visualization of vibration. Attorneys will **inevitably** misuse such water bottle observations to imply a **quantitative** (i.e. amount of vibration) relationship, where no quantitative information can be determined or offered that way, for multiple reasons.

Quantitative data from a cell phone or tablet computer could be particularly valuable as a backup and a deterrent. In a case of the sort I was involved in, the vibration monitoring "professional" "lost" about a quarter of the data, including that for all of the monitored days on which the vibrations were most intense. His report to the the contractor, written just over a month after the data were recorded, and some two years before the computer crash claimed to be at fault for the loss, was also missing any data for those days. Having competing data of your own would provide strong encouragement for "re-discovery" of the contractor data.

Just how valuable your data might be will depend on the care with which you have set up the monitoring, your knowledge of its meaning and your ability to depict and explain the results. You can expect that such data would be challenged, with or without valid cause. Hence, you will want to acquire DIY data as carefully as you can, perhaps using the tips above. Unless you calibrate your device properly (as above), the data you acquire should be considered **semi-quantitative**. They can be used to establish the presence of vibration and the relative sizes of vibrations, even if the absolute value of any specific vibration might be subject to some dispute in the absence of proper calibration.

The CVDG Professional Edition has a sizable part of its much larger content devoted to acquiring, analyzing and understanding vibration data. You can get it at http://vibrationdamage.com/order_the_cvdg_pro.htm.

Noise Monitoring

Most tablets and many cell phones have either microphone inputs or built-in microphones. Since sound recording is often used in the context of construction and blasting monitoring to evaluate noise nuisance concerns, your tablet or cell phone may offer you a way to get noise data, as well as vibration data. Just as with vibration, there are numerous free apps for sound monitoring, running on just about any small device operating system.

Other Uses of Small Device Sensors

Small device sensor use is an area of considerable current development for very different purposes, particularly in developing countries, where more conventional monitoring equipment is difficult to obtain at acceptable prices. We can expect to see more use of the sensor suite in cell phones and tablet computers in all kinds of settings. For now, the homeowner dealing with construction damage issues, potential or actual, has tools available to him that didn't exist a few years ago. These can help him change the discussion in a possible vibration damage situation.

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1. ISEE Field Guidelines for Blasting Seismographs, 2009 Edition, p. 4

Vibration Measures

Although seismographs are most commonly used in vibration monitoring, other kinds of instrumentation can also be used to detect and measure ground vibration. They provide different, but complementary, information to that provided by seismographs. This section of the CVDG will discuss what those other vibration monitoring methods are, how they work, what they measure and how they relate to one another. The chapter ends with comparisons of various scales for ground movement intensity. Some topics in this chapter are also discussed in the CVDG chapter, DIY Monitoring, available only in the free CVDG PDF download and in the CVDG Professional Edition, not online.

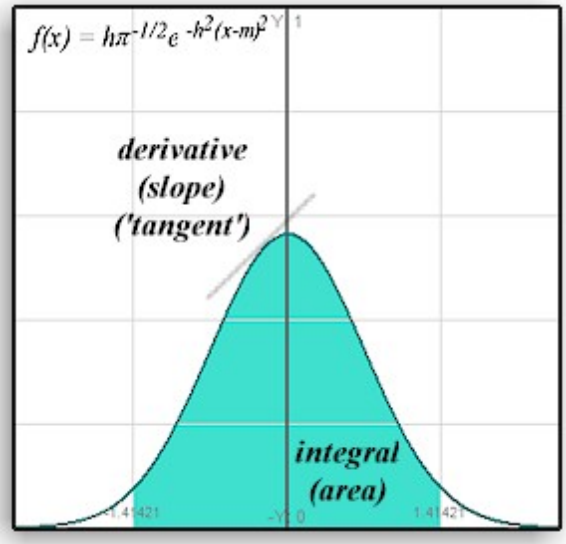
Vibration Measurement Types

There are several different ways of measuring vibration and its effects. These measure vibration using very different means and providing different, but interrelated, types of information. A brief summary of the types instrumentation and what they measure follows:

- **Seismometers and Seismographs** - These work via magnet-in-coil devices which measure ground movement **velocity** directly, in units of inches per second (in/sec) or millimeters per second (mm/sec). Ground movement velocity is considered in the scientific literature to be the most reliable predictor of damage potential.
- **Accelerometers** - These measure **acceleration, which is the rate of change in the velocity,** specified in inches per second per second (in/sec^2) or millimeters per second per second (mm/sec^2). The higher the acceleration is, the higher the final velocity will be at any given point in time. There are many ways to measure acceleration, but modern accelerometers for typical accelerations are **silicon micromechanical devices** fabricated using the same techniques as those used in computer chip manufacture. We are all under a nominal vertical acceleration of about 9.8 m/sec^2 in "free fall", due to normal Earth gravity.
- **Displacement Gauges** - Displacement gauges bridge an existing crack and measure the change in the crack width in inches or millimeters. Note that there is no time element at all in describing the displacement.
- **Strain Gauges** - measure the amount of mechanical deformation caused by applied forces, in this case, those of vibration, usually using the electrical properties of a wire or semiconductor under tension. Strain provides both an estimate of vibration effects and the likelihood that those effects will manifest themselves as damage. The higher the strain, the greater the chance of damage. Strain is a measurement of the effect on the structure, not of the vibration intensity itself.

These measurements are closely related, but not identical. However, one can interconvert between some of them using the ideas of (gasp!) the calculus.

A Very Brief Introduction to Calculus



Sir Isaac Newton and Gottfried Leibniz are known as the co-inventors of calculus. Newton was a scientist and Leibniz a mathematician, but they both developed much the same tools independently from their different standpoints. The calculus has two major branches, **differential calculus** and **integral calculus**. The practical difference between the two is about what they can tell us: **differential calculus** is about rates of change (tangent point slopes) of mathematical curves, while **integral calculus** involves determination of areas under parts of mathematical curves.

To see these differences graphically, let's look at the diagram at right, which shows a plot of the normal error function curve often known as a "Gaussian". Such a curve plots the expected range of scatter and relative numbers of the data points for measurement of any quantity following this error curve. Time can be the variable in such a curve, but, most commonly, is not. In vibration monitoring raw data plots, time is almost always the variable on the horizontal axis, although FFT plots will have frequency as the horizontal axis.

Application of differential calculus ("**differentiation**") to any curve produces the **derivative**, which, for relationships of properties with respect to time, is denoted by the $^{dx}/_{dt}$ symbol. X denotes whatever quantity is varying with time. When speaking of vibration raw data, x would be the displacement. The derivative is simply the slope of the curve at a "tangent" to it at any given point (i.e. where a line intersects the curve at one and only one point and does not cross it), as shown in the graphic. It is the rate of change of that curve at that point. It is possible to apply differentiation more than once. When applied twice with respect to time, it is written as $^{dx}/_{dt^2}$

The **integral**, denoted by the stylized S symbol, $\int$, is simply the area under the curve between specified limits for "**definite integrals**", as shown in the teal area under the Gaussian curve above right. In this particular case, the integral is taken from minus 2 standard deviations (**2s**) to plus 2 standard deviations, $\int^{+2s}_{-2s}$. Mathematical curves like the one shown in the diagram often have specific known derivatives and integrals ("**analytical solutions**"), which are themselves other mathematical functions ("**indefinite integrals**"), which one evaluates by putting the ranges into the functions, upon which, they become "**definite integrals**". Real-life data plots, like that from vibration monitoring equipment, almost never have such an analytical solution. So, they must be differentiated or integrated numerically.[1]

Interrelationships Between Vibration Measures

Displacement is a change in position about a central point. Although the position changes, displacement does not take into account the time variable at all. Hence, in the

context of vibration measures, displacement is simply the x in the notation written above. **Velocity** describes the rate of change of the position x with respect to time; it is the first derivative of position with respect to time, $^{dx}/_{dt}$. **Acceleration** is the rate of change of the velocity with respect to time. Since velocity is the first derivative of position with respect to time and acceleration is the rate of change of velocity, acceleration is the second derivative of position with respect to time, $^{dx}/_{dt^2}$.

These relationships give us a practical way of inter-converting between the different measurements of vibration. For example, to convert an acceleration vs. time vibration curve to a velocity vs. time curve of the sort commonly used in vibration monitoring, we must integrate it to determine the area under the curve in each measurement period. When these areas are plotted, they show velocity vs. time. The conversion methods between the various quantities are shown in the following table.

Convert from:	**To: displacement**	**To: velocity**	**To: acceleration**
displacement		differentiate	differentiate twice
velocity	integrate		differentiate
acceleration	integrate twice	integrate	

Calculating a slope between data points is straightforward. The integral is a bit more difficult. There are a number of different ways of approximating the area under a curve (integral), when an analytical solution is unavailable. These include rectangle (several different versions) trapezoid, Romberg, and Gauss approximations, among others. One may choose one or the other, based on the shape of the curve being integrated and the degree of accuracy desired. The rectangle and trapezoidal approximations are most readily implemented in a spreadsheet containing vibration data.

Keeping in mind that integration means determining an area and differentiation means determining a slope, one can use a spreadsheet showing the velocity vs. time vibration data (of the sort gotten from a seismograph) to determine total displacement simply by having the spreadsheet calculate the areas of under the velocity vs. time curve at each measurement point. Since the displacement is a measure of vibration exposure, a simple spreadsheet rectangle numerical integration of that sort is the basis for the vibration exposure calculations described in detail in the CVDG Pro page, Vibration Exposure and summarized on the CVDG page, Resonance and Fatigue.

One can also take acceleration data of the sort produced by accelerometers and convert to velocity vs. time by the same numerical integration process. These relationships are important for entirely practical reasons. They allow us to take data from one type of device and compare it with data from another entirely different device. This opens up new ways for the homeowner to protect himself during construction by applying the solid state, 3-axis accelerometers present in most cell phones and tablet computers to do his own vibration monitoring cheaply and with a minimum of hassle. **For more on how to use a phone or a tablet to do your own monitoring, see the CVDG page, DIY Monitoring**.

Ground Movement Scales

Just about everyone is familiar with the **Richter Scale**, a measure of the source strength of earthquakes. Although the Richter magnitudes can be related to effects on structures

and people, that is not the quantity they measure. Estimated Richter magnitudes are distance-independent, while the ground movement velocities measured by the seismograph are not. In effect, the Richter Scale estimates earthquake energy at its source, correcting for distance, by using measurements from multiple seismographs at various distances to calculate and correlate the source energy.

A less well-known earthquake measurement scale is the "**Modified Mercalli**" scale. It uses arbitrary Roman numeral designations to estimate and describe strengths of earthquakes based entirely on the observed effects on structures and people. While there are correlations between the Richter and Mercalli scales, those correlations are not exact, because they measure intensity entirely differently.

Ground vibration velocities from vibration monitoring are distance-dependent and specific to a given location with respect to the source of the vibration. Locations at exactly the same distance from the source often show different measured ground movement velocities. Since vibration velocities can be correlated with damage to some degree, one can use the damage effects to provide a bridge between vibration monitoring PPV's and, for example, the Modified Mercalli Scale. For example, a vibration at or slightly above the OSM blasting limit of 0.75 in/sec would probably rate somewhere in the range III-V on the MM scale, depending specifically on the vibration frequency distribution. However, such correlations are, at best, approximate, since the correlations relate to absolute vibration intensity in different ways. The USGS has a good lay summary of earthquake scales for those who want to know more.[2]

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1. It is also possible to take derivatives and integrals with respect to single variables of quantities which are affected by multiple variables. These are called "partial" derivatives or "partial" integrals. The first partial derivative of a quantity x with respect to time is denoted by $\partial x / \partial t$. Partial derivatives show up everywhere in science, because most physical quantities depend on more than one variable.

2. *The Severity of An Earthquake*, United States Geological Survey, U.S. GOVERNMENT PRINTING OFFICE: 1989-288-913, http://pubs.usgs.gov/gip/earthq4/severitygip.html

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More Information

The Internet has an immense amount of information for people who may be pursuing a vibration damage claim on their home. Much of this information is available in downloadable PDF format; you will need a copy of the free Adobe Reader to view or print PDF files. Following are some starting links to a few of the most valuable ones:

- OSM Blasting Download Page (http://www.osmre.gov/resources/blasting/ARBlast.shtm) - This page is the best one-page source of blasting-related vibration documents on the Internet. You can find here PDF versions of **USBM RI 8507 and other USBM studies**, the **OSMRE Blasting Guidance Manual**, which includes the OSM standard, and much more, for free.

- FTA Noise and Vibration Manual (http://www.fta.dot.gov/documents/FTA_Noise_and_Vibration_Manual.pdf) - An invaluable source of information on traffic and road construction related ground vibration. It includes the FTA standard and much more.

  Although the whole manual is useful, most readers will find Chapter 12 to be particularly valuable.

- ISEE Field Practice Guidelines For Blasting Seismographs 2009 Edition (http://www.isee.org/media/pdf/FieldPracticeGuidelinesRev03_01_10.pdf) - The "bible" on proper setup and use of a blasting seismograph. Since most vibration monitoring seismographs are designed as blasting seismographs, this is important for homeowners to read in understanding vibration monitoring.

- Minimizing Construction Vibration Effects (http://www.jurispro.com/files/documents/doc-1066204429-article-1460.pdf) - A good summary article regarding construction vibration effects and damage

This short list is far from exhaustive, as there are literally hundreds of relevant documents available, but these are good starting points in understanding construction vibration damage issues. A listing of all of the documents cited in the CVDG can be found on the Cited Literature page.

Cited Literature

Many pages of the two versions of the CVDG bear footnotes with short-form literature citations. For convenience of readers, the complete document citations are collected below. Most can be obtained readily on the Internet in PDF or HTML format by searching for the titles and downloading them. This is only a small fraction of the documents whose content has some relevance to construction vibration damage, but should constitute a good basis for someone just learning the field.

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Fundamentals of Physics, D Halliday and R. Resnick, John Wiley & Sons, 1970, ISBN-13: 978-0471344308

Jones & Stokes. 2004. *Transportation- and construction-induced vibration guidance manual*.
June. (J&S 02-039.) Sacramento, CA. Prepared for California Department of

Transportation,
Noise, Vibration, and Hazardous Waste Management Office, Sacramento, CA.

NMDOT Standard Specifications for Highway and Bridge Construction, Section 617, 2009

OSM Blasting Performance Standards, 30 Code of Federal Regulations, Sec. 816.61

OSMRE Blasting Guidance Manual, Michael F. Rosenthal and Gregory L. Morlock, 1987

ISEE Field Practice Guidelines for Blasting Seismographs, 2009 Edition, International Society of Explosives Engineers

GROUND VIBRATIONS CAUSED BY ROAD CONSTRUCTION OPERATIONS, D J Martin, Department of the Environment, Department of Transport TRRL Supplementary Report 328: Crowthorne, 1977

Minimizing Construction Vibration Effects, M. R. Svinkin, Practice Periodical On Structural Design and Construction, Vol. 9, No.2, May 1, 2004, ASCE, p. 108

Standard General Conditions of the Construction Contract of the Engineers Joint Contract Documents Committee, National Society of Professional Engineers for EJCDC, 2007

BLASTING VIBRATIONS AND THEIR EFFECTS ON STRUCTURES, Harry R. Nicholls. Charles F. Johnson. and Wilbur I. Duvall, United States Bureau of Mines Bulletin 656, 1976

RECENT DEVELOPMENTS IN PROPERTY INSURANCE LAW, W. A. Schreiner, *et al*., Tort Trial & Insurance Practice Law Journal, Fall 2011 (47:1), pp. 481-482

Structure Response and Damage Produced by Ground Vibration From Surface Mine Blasting, D. E. Siskind, M. S. Stagg, J. W. Kopp, and C. H. Dowding, United States Bureau of Mines Report of Investigations 8507, 1980

Review of Criteria for Estimating Damage to Residences From Blasting Vibrations, Wilbur I. Duvall and David E. Fogelson, United States Bureau of Mines Report of Investigations 5968, 1962

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Vibration Problems in Structures: Practical Guidelines, Hugo Bachmann, Walter J. Ammann, Florian Deischl and Josef Eisenmann, Springer, 1994, ISBN-13: 978-3764351489

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CVDG Pro Pages

Construction Vibration Damage Guide, Professional Edition

Page Summaries

The *Construction Vibration Damage Guide, Professional Edition* (*CVDG Pro*, ©Copyright 2013-2014 John M. Zeigler) is designed for use by construction businesses, law firms, project sponsors, homeowners and others who need more extensive technical information and help to deal with construction vibration damage claims. It includes all the content of the free *CVDG for Homeowners*, but is expanded in numerous ways. The additional pages unique to the CVDG Pro are not offered online. They are only available by purchase from our Order the CVDG Pro page at http://vibrationdamage.com/order_the_cvdg_pro.htm.

However, some readers of the CVDG free edition for homeowners may be interested in learning a bit more about the additional topics covered in the Professional Edition. To that end, the introductory paragraphs for each of those pages are reproduced below

CVDG Pro Page Summaries

For Project Sponsors

This page offers some non-legal tips for project sponsors on how to avoid lawsuits and, in the process, keep surrounding neighbors happy, or at least tolerant of, the construction work. These tips are based on our own experiences watching a sponsor make about as many "mistakes" as possible.

Using a Vibration Monitor Firm

A basic description of vibration monitoring equipment, its use and issues to look for in vibration studies is given in the CVDG page Vibration Monitoring. However, **a responsible contractor needs to know what he should seek in retaining a subcontractor for vibration monitoring**. Improperly done monitoring is essentially worthless in a defense against a vibration damage claim. Poorly reported monitoring can largely invalidate otherwise well-done vibration monitoring. This page provides additional description and detail on what a contractor should expect in hiring a vibration monitoring subcontractor, some matters of which he should take notice during monitoring, and how to understand

the data and assure that it is properly reported.

Reading Vibration Data

This page provides a brief overview of typical vibration monitoring reports - how to read them and what they can tell you. Although different analysis software will produce vibration data reports which look slightly different, the underlying vibration data are similar for all blasting seismographs. The reports are **not** the data, just ways of presenting different aspects of the data. The usage of the term "report" on this page is analogous to database software terminology, where the various report types from the database constitute different ways of looking at and organizing subsets of the data.

Vibration Data Issues

Properly used, blasting seismographs produce reliable measurements of construction vibration, at least **until their memory fills with data**. If you are given vibration reports from such a seismograph in the context of your claim, it would be wise to read and understand them. **If a seismograph is placed in or near your yard, document its location on video or with photos on every such occasion, with close-ups of the transducer head to show details of its installation.** If the seismograph is being improperly used or critical data are being withheld, this documentation will be critical to establishing the facts. Contractors who have hired vibration monitoring firms should be alert for the kinds of problems discussed below, since **such mistakes could render their vibration monitoring unreliable, unsupportable and scientifically meaningless**.

Vibration Data Handling

Blasting seismographs, when used for construction vibration monitoring, can produce immense amounts of data over the course of the work. Because the vibration monitoring firms who acquire these data work for construction firms in most cases, it's a strong possibility that the seismographic data won't be properly or fully analyzed by anyone, excepting someone whose house has been damaged by the construction vibration. This page discusses how to analyze the data properly and in the most efficient manner. It assumes that the reader will have previously read our CVDG Pro page, Vibration Data Reports, which describes what the printed data look like and how they can be read.

Vibration Data Analysis

Our page, Vibration Data Issues, has general, relatively non-technical, descriptions of some of the problems that can arise with improperly acquired and documented vibration monitoring data. Another page, Vibration Data Handling, discusses general strategies for obtaining and analyzing a substantial body of relevant vibration monitoring data. Here, I will go into some greater detail on the technical issues that should be investigated in a thorough analysis of vibration monitoring data. Generally speaking, I will not duplicate the content of the pages referenced above, so this page should be used in conjunction

with those.

Vibration Data Analysis Tables

I have discussed in the CVDG Pro page, Vibration Data Analysis, how to analyze a vibration data set efficiently. Reporting Vibration Data describes how to report it properly. Other pages in the CVDG Professional Edition describe what kinds of issues to look for in doing that analysis. On this page, I will indicate what kinds of tables, like the examples pages at left, might be generally useful in a careful analysis of vibration data, based on my experience in a vibration damage case which actually went all the way to trial.

Reporting Vibration Data

The CVDG Pro page, Vibration Data Issues, has a general discussion of errors in installation and use of a blasting seismograph that are sometimes seen. This topic receives a detailed treatment in the CVDG Pro page, Vibration Data Analysis. However, the conclusions drawn from vibration data, and the process by which they are generated, are at least as important as the data themselves. Even properly obtained data, if improperly interpreted and reported, are just as useless and misleading as bad data. On this page I'll talk about a few mistakes in use, interpretation and reporting of vibration monitoring data to contractors and others. I'll also comment on the kinds of information that should make up any thorough scientific report on vibration monitoring.

Statistics and Vibration Damage

Scientific data in the real world have neither 100% **accuracy** nor 100% repeatability ("**precision**"). This doesn't mean that the science is badly done or unreliable. All measurements are subject to some statistical variability, including those relating to vibration damage probabilities. Because the real world is "messy" in this sense at least, scientists routinely use statistics to analyze and understand the meaning of data of all sorts. Proper statistical analysis is not only scientifically fitting, but necessary, in understanding vibration damage data, as in other scientific fields. Below I offer, in layman's language, an explanation of basic data analysis statistics, especially in relation to **the use of statistics in setting vibration standards and the proper use of those standards**.

Vibration Signatures

All too often, vibration monitoring data are simply "analyzed" by comparing the maximum intensity (PPV) to a compliance plot of some sort, whether an appropriate one or not. However, a more careful analysis of vibration waveforms and frequency spectra can be a powerful tool in tracing ground vibration damage sources and causation. Different kinds of construction equipment and different kinds of activities leave different vibrational signatures on a seismograph trace, which can be useful in identifying the cause(s) of

events. On this page, we'll provide a few examples of some of these types of signatures and show how they can be used in a vibration damage case to determine or disprove the cause of a given vibration.

Vibration Exposure

It is widely understood that construction vibrations pose special problems relative to the better-studied blasting vibrations. This is due to their far longer durations, lower frequency distributions, and intensities large enough to be of concern. Unfortunately, there is little discussion in the scientific literature of vibration as to how one might put numbers on **relative exposures to vibration from blasting and construction**. Because correlations between short-duration blasting vibrations and damage are far better established than correlations between long-duration construction vibrations and damage, providing a method to determine **total vibration exposure will only help understand the size and nature of the problem, not how the exposure correlates to damage**. However, since such a means of determining relative exposure to vibration is so desperately needed, I will offer such a method here.

Applying Vibration Standards

The CVDG, in both the free edition for homeowners and the Professional Edition, has much discussion of the inadvisability of use and scientific unsuitability of blasting-based vibration standards in non-blasting construction environments. Fundamentally, the reason behind this is that **construction vibrations last far longer and are repeated far more frequently than those from blasting**, even at mines and quarries where blasting is done with some frequency. Blasting vibration standards, like the OSM standard and the USBM RI 8507 study recommendations from which it is derived, recognize this limitation explicitly. If we take as a given that the only scientifically supportable way of applying vibration standards is to use construction-based standards (e.g. the Swiss machines and traffic standard, the U.S. FTA standard) in construction environments and blasting-based standards (e.g. OSM, USBM RI 8507, the Swiss blasting standard) in blasting environments, then what standards should be used in "mixed" or otherwise different construction environments, at least from the standpoint of damage to structures? On this page, I'll discuss what I believe are the scientifically supportable ways of choosing and applying vibration standards.

Vibration and Homes

Human caused ground vibration, *per se*, does no damage - until it interacts with structures. The way and the efficiency with which it affects structures determines both the extent of damage and how far away from the source homes may be harmed. Here, I discuss what these interactions are and what they mean for vibration monitoring and the scientifically valid conclusions that can be drawn from it. I also discuss some of the areas in which research has provided only limited insight.

Inferring Vibration Levels

In some situations, you may not be able to get vibration monitoring data, either because it is refused to you or because it is "lost" by the monitoring firm or contractor. Of course, there may also be examples, like the one with which I'm most familiar, where the vibration data are largely or entirely unreliable. Fortunately, the literature of vibration damage provides some ability to infer vibration levels in cases where there are no useful vibration measurements recorded during critical operations or even where they have been recorded, but "lost". Below, I discuss some means by which you can make these critical inferences, based on the types of damage you can see, even when data are lacking.

Mitigating Vibration

It is possible to mitigate construction vibration and damage by using procedures and equipment appropriately and judiciously, taking into account the presence of structures and people nearby the work site. Such mitigation procedures are well-known and described in the vibration damage scientific literature and in government regulatory documents. It may not be possible to eliminate absolutely **all** vibration and damage from construction operations. However, **any failure of the contractor to utilize equipment correctly and to adopt mitigation measures prior to project start should be a source of concern and questioning**. On this page, I'll discuss and provide references to some publicly available standards and studies which describe vibration mitigation procedures.

Working With An Attorney

In many, perhaps most, examples of vibration damage claims, an attorney will be involved for one or both sides (see the CVDG page, Involving An Attorney, for more information). Attorneys are both very busy and highly paid, so working with the attorney with maximum efficiency and minimum wasted time is in your financial and personal interest. You can help by researching the claim (see Researching A Claim in the CVDG Pro), educating the attorney on the science of vibration damage, analyzing vibration data, providing documents which support your position, preparing documentation (e.g. videotape of construction work and damage), and answering questions quickly and correctly, as well as many other ways. In this chapter, I'll discuss some of the ways in which you can help your attorney move your case forward most advantageously and with less expense to you.

Fourier Transform

This page is for those who would like to understand how vibration data can be analyzed mathematically to extract frequency data and why such an analysis is necessary to understand the vibration data. While the frequency information itself is critical, and methods of displaying it have different uses, the general means by which it is extracted need not be understood by everyone. If you are willing simply to accept the frequency distribution results from Fourier Transform of vibration data, you can skip this entire page or you can defer reading it to a later time.

Expert Opinion

Any competent litigator will have much expertise and experience in finding, using and questioning experts. Such an attorney will know best how to choose and use his experts, based on the facts in a given case. However, expert testimony in vibration damage cases has some unique technical aspects with which both the attorney and the expert should be familiar. Our CVDG page, Litigating, has some general tips on choosing and using experts in these cases. On this page, I'll talk about expert opinions in vibration damage cases and how to assure that they correctly reflect the state of knowledge and opinion in the field.

Handling A Claim

Your probability of success in resolving a vibration damage claim through a fair settlement depends as much upon your attitudes and behavior as it depends on the facts of the damage and your ability to link it to construction operations (CVDG Pro). This page discusses how to handle your claim, mostly before you retain an attorney. You are particularly vulnerable to "mistakes" you might make during the period before you get representation, so you must behave with care and calm. If you have an attorney, ask his or her advice on your interactions with others and follow it.

Conditions Documents

This page has some possible conditions documents that might be used to control visits to view vibration damage and keep records of which parties receive what evidential materials. Without these or similar documents, representatives of opposing parties can significantly intrude upon your privacy under the guise of documenting damage. You can copy the text from the documents and modify them to suit your own needs and wishes.

Settlement

If you can arrive at a reasonably fair settlement of your vibration damage claim, it will save you time, money and untold stress and irritation. This page will discuss some of the aspects of coming to a fair settlement.

Damage Causation

If you make a claim for vibration damages, whether or not you litigate the claim, you will need to prove damage causation. Causation is just a fancy legal word describing a cause and effect relationship between a negative result of some sort and actions taken by others. By definition, cause and effect are related in time; an effect must follow a cause.

Relationships in time are critical to establishing causation, but are not, by themselves, sufficient to make a causal link. **You must show that the damage was not simply**

coincidental in time with construction work, not caused in some other way, not pre-existing and directly linked to known construction activities. On this page, I'll discuss some of the ways in which you might establish a causal link in a vibration damage claim.

Counterarguments

Sometimes, contractors and their "experts" will try to explain away vibration damage, rather than explain it. Such arguments may be scientifically supportable in some examples and situations. This page has a discussion of some of the most common counterarguments that are made in construction vibration damage cases and some ways in which a homeowner might address them.

Giving Testimony

Giving good testimony is mostly about preparation and personal strength. Your attorney will help prepare you to give testimony, both in deposition and trial. Listen to and follow his advice. Prepare yourself well on the facts and the most important documents, so that you can give testimony with confidence and accuracy. Since the opposing attorney has virtually all the advantages, you must bring to bear your honesty, integrity and knowledge to maximize your effectiveness in testimony.

Researching A Claim

While proper documentation of damage and a good understanding of vibration damage as a scientific field are important, they are probably not enough, by themselves, to pursue a vibration claim for a substantial amount of damages. A large law firm will have some capabilities to do this for you, but it will be expensive and may not be as thorough a job as you would do. On this page, I'll discuss some of the areas a homeowner with damage might want to look into to develop a claim. Since different claims have different issues, this description can't be all-inclusive, but should give you a start and perhaps, a few ideas.

Production Requests

Preparing proper and complete production requests can be critical to understanding the facts in the vibration damage case and can help toward getting a favorable resolution. While any competent attorney can do a good job in this task, there are some scientific and technical issues which might escape notice. Following is an extensive, though partial list of some possible production requests an attorney might consider making of a contractor defendant.

More Documents

Reproduced from the More Information page of the free CVDG for homeowners, directly below are some basic links to important technical documents in a vibration damage case. Following that are additional references and document types that may be valuable in preparing a vibration damage case.

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Closing Thoughts

Construction is both a part and a sign of progress in society. No reasonable person would argue that **all** of it should be stopped. Most construction contractors are honest, decent people who are trying to do a professional job, usually under significant time constraints, at the lowest possible cost. Sometimes, some very limited vibration damage in a residential neighborhood can occur, even for work done by the most well-meaning and careful of contractors. Such well-meaning, respect-worthy contractors will usually be reasonable about resolving damage claims, without subjecting the injured party to much more than the minimum amount of abuse and worry.

Unfortunately, not all contractors can be said to fall into that category. These other folks, sometimes with the support of the people who fund them, will ignore recommended safe methods, Federal regulations, equipment operation manuals and their own policies, damaging your home and many others. If your house gets spoiled by one of those, you're in for an unpleasant fight.

Significant vibration damage is neither necessary nor unavoidable. There are well-known, free, publicly-available and respected documents which describe how to mitigate vibration so as to forestall damage. While not all construction projects cause damage to nearby structures, it is widely accepted among those with some understanding of the relevant science that damage is possible under some circumstances. It is, perhaps, even probable when safe operation procedures, accepted methods, company policies and mitigation means are ignored.

If you have a construction vibration damage claim, you will probably have to deal with **unscientific, unsupported and self-serving biases** to the effect that "construction can't cause damage". These seem prevalent among those involved in construction-related activities. While **it is undoubtedly true that not all construction work causes vibration damage**, blanket statements that damage is "impossible" are both unproven and unprovable logically. Many of the people who offer, and, perhaps, genuinely believe such views seem completely unaware that any basis for them is extremely limited, scientifically weak and often contradicted both by experience and scientific studies. **Such attitudes may actually contribute to damage,** by giving construction workers and on-site supervisors a false sense of security about the potential consequences of their work.

To the extent that there is any foundation at all for such opinions, it rests largely on the selective reading and misapplication of blasting vibration standards and studies, which are of limited value in non-blasting construction vibration settings. Although short duration blasting vibrations have been broadly and, for the most part, well-studied, **there is too little directly applicable scientific study of long duration (i.e. more than a**

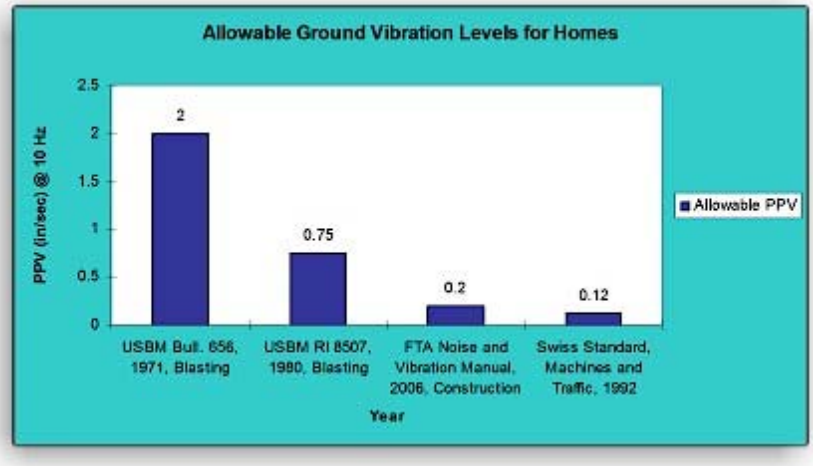
few seconds) or continuous construction vibration, in spite of the obvious potential importance of such work and the known critical differences in frequency distribution and duration between construction and blasting vibration. A careful reading of the far more extensive blasting vibration damage literature is more than sufficient to raise many questions about whether construction vibration damage might be far more prevalent than acknowledged or imagined by those doing the construction work or those hired by contractors to endorse their positions.

Although the subject of some current work, information on construction vibration damage is still dominated by blasting-related studies. These are useful and valuable in a general sense, but have clear, and admitted, limitations in construction settings, where the vibrations are long-lived and of generally lower frequencies than blasting vibrations. Calculations of total displacement, from seismographic data in a road construction job, show that **construction produces tens to well over a hundred times as much accumulated movement as worst-case blasting over comparable time intervals**.

Blast-created source vibrations usually last for less time than the natural duration of vibrations generated in the home, allowing the home vibrations to die well before the next blast. It is unclear how far blasting vibration damage results can be "stretched" to include construction vibration durations. These are typically much longer than the natural time of persistence of vibrations in homes, allowing potentially damaging resonance amplification effects in the structure to be maximized. These differences in vibration effects between blasting and construction vibration are poorly addressed in existing research. Worse yet, existing studies don't directly address how resonance effects may be enhanced by long-lasting construction vibrations at all.

Vibration monitoring reports, usually done at the behest of a contractor facing vibration damage claims, often base their conclusions on highly selective analyses of partial data, which lack the information needed to assess the real potential for damage from resonant enhancement of vibrations. The necessary information is usually present in, or derivable from, the raw data, but, too often, either is not understood or not reported by the vibration monitoring sub-contactor. For these and many other reasons, **a home owner who has been given conclusions from vibration monitoring should get the underlying data and analyze them himself**, or have someone else qualified to do it analyze them for him, to assure that the conclusions offered are really valid.

What can be said with certainty is that, even in blasting studies, there has been a steady downward trend in vibration velocities (PPV's) considered "allowable", as more and more data have been acquired (see diagram at right). This fact alone suggests that **caution and open-mindedness are well-advised when**



considering construction vibrations and their effect on homes.

Just as claims of the "impossibility" of construction vibration damage are clearly false, **not every instance of damage in a home or structure can be blamed legitimately on construction**. Vibrations in a home that many people find disturbing are often insufficient to produce damage. The presence of, perhaps, under ten hairline cracks in drywall, which you notice during the construction, is not proof that construction is responsible for them. Weather and heat/cool cycling, aging, and, in highly localized areas within a home, even human activities, can all cause hairline cracking in drywall or plaster.

Neither is every type of construction activity equally hazardous from the standpoint of potential for damage. **Those activities which involve impact (e.g. pile-driving, pounding) or impact-like (vibratory compaction, driving tracked heavy equipment) interactions with the ground are of particular concern. This true because of the broad frequency distributions associated with impacts, apart from or in addition to their relative velocities, which just about assure resonant amplification of ground vibrations in the home.**

On the other hand, sometimes damage is so extensive in your home and so widespread in entire neighborhoods, that large, documented construction vibrations are just about the only consistent explanation. You will still need considerable evidence to prove a vibration damage claim, correlating the appearance of the cracks with construction vibration. Some of this you can provide through video, photos taken before the damage, testimony of neighbors, etc.; other evidence can be provided by experts with whom you consult. Whatever your level of damage, you have to **weigh the chances both of proving construction causation and winning significant reimbursement** against the time, money and general stress that getting such reimbursement may cost you.

Ideally, all vibration damage claims would be resolved fairly and amicably, without intervention of the legal system. **A fair settlement saves time, money, focus and untold stress for all the parties**. However, if the total damage loss is sizable, you may not have any choice but to obtain legal representation and, perhaps, pursue a lawsuit. Construction insurers make decisions about settling larger claims based mostly on a balancing of the cost of settlement vs. the cost of a legal defense, not on whether it's "the right thing" to do or, even, whether their position has been supported in past court rulings.

Nonetheless, you can pursue, and win, a damage claim, if you have a legitimate, well-documented claim and the determination, knowledge and resources to see it through. If you and your claim have these qualities, I wish you success. I hope this *Guide* will help you get through that process with less unnecessary hassle and expense.

Every time a dishonest and/or irresponsible contractor fights a **legitimate** vibration damage claim and loses, the world becomes a bit **safer for everyone's homes and property**. Every time an insurance company has to absorb a claim loss, because it is proven that the contractor policyholder repeatedly did things it knew were **inappropriate, risky and in direct contradiction to its own policies**, the higher the insurance costs become for such people and the more likely it is they will mend their ways. Contractors must report litigation and claims against them in proposals. Although

some conveniently forget to do so, word of mouth can produce much the same result. **A real and manifest sense of responsibility on the part of contractors and project sponsors to those who live in their work areas can only be positive for all concerned.**

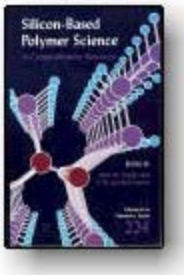
Societal progress does not force a choice between the benefits of construction and the rights and security of individuals who just happen to have homes or buildings around the construction. The choices people and organizations make about how to bring about what they view as progress will determine whether others are hurt unjustly and unnecessarily by it. As in many other areas of human endeavor, the ends cannot be used to "justify" absolutely any means. Since contractors know their own business far better than those who live around their work sites, it is the responsibility of contractors to inform themselves about and follow widely accepted and justifiable policies, rules, procedures and truly appropriate standards in conducting their work. **There is simply no excuse for causing extensive "collateral damage" in a construction job.**

While it can't cover every aspect of construction vibration damage, I hope that the *Construction Vibration Damage Guide for Homeowners*, and the scientific, litigation and personal experience that led to it, has been of value to you. I've left out a good deal of material, because it may be too technical for, or of limited interest to, some readers of the free CVDG. Much of that content that can be found in the *CVDG Professional Edition*.

I would be happy to hear your comments and suggestions for improvement of this **free, public service resource**. You can send them to drzeigler@vibrationdamage.com. I will read them, respond and incorporate the responses in later versions, to the extent possible. **Thanks for taking the time to read the** *Guide***.**

CVDG Author

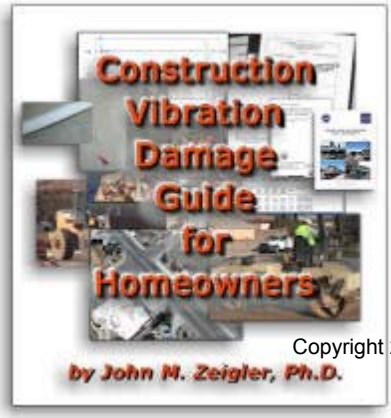
Construction Vibration Damage Guide for Homeowners - About the Author



Dr. John M. Zeigler has an earned Ph.D. in Organic Chemistry from the University of Illinois, a highly-ranked chemistry graduate program, and is a member of the Phi Beta Kappa Society. He is co-editor and co-author of an ACS Advances in Chemistry reference volume on silicon-based polymers, *Silicon-Based Polymer Science - A Comprehensive Resource*, shown at right, and has been a long-time member of the Editorial Advisory Board of the *Journal of Inorganic and Organometallic Polymers*.

A co-recipient of an international IR-100 (R&D-100) award for the development of polysilane self-developing photoresists, he is also the **inventor or co-inventor on over 30 U.S. and foreign patents**. He has **published over 60 papers** in the scientific literature and been an invited speaker at scientific meetings and universities over 100 times, as well as serving as an organizer of several international scientific meetings. Dr. Zeigler has also worked in silicones and other silicon-based polymers, conductive polymers, receiving several patents in that area, super-acid catalysis, polymer photodegradation, and organic chemistry research.

As a scientific consultant, he has provided expertise on polymeric materials and applications to both Fortune 500 and smaller companies. He has been involved in **litigation support work for nearly 20 years**, primarily in various aspects of medical devices materials, manufacturing and quality control, in addition to scientific consulting and other activities. A *curriculum vitae*, listing publications, invited presentations, patents, testimony and other relevant materials is available. A separate business website, http://silchemy.com, has more information on his background and work.



Dr. Zeigler developed considerable **scientific and litigation expertise in construction vibration damage,** arising from extensive damage done to his home during a road reconstruction project. He was the primary scientific consultant throughout that case. The consulting included damage and scientific documentation, testimony, expert and attorney scientific preparation, vibration monitoring data

analysis, and case assembly all the way through trial. Although not a retelling of his case, the CVDG, in both the free Homeowners version and the extended Professional Edition, is based on what he learned in that nearly 4 year experience.

See if We Can Help You!

If you're interested in exploring whether we can help in your construction vibration damage issues, as a homeowner, an attorney or as a responsible contractor, contact us now. Initial consultations are free and confidential, without obligation. You can reach us by e-mail to drzeigler@vibrationdamage.com or visit Dr. Zeigler's company site at http://silchemy.com.

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